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ADDITIVE MANUFACTURING AS A FORCE MULTIPLIER IN DEPLOYED OPERATIONS

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AIM

1. The use of 3D Printing, or Additive Manufacturing (AM) as it is formally known, could revolutionize supply chain management for Canadian Armed Forces (CAF) deployed operations. The aim of this service paper is to provide a recommendation regarding the use of Additive Manufacturing on deployed operations to the Chief of Staff (COS) Support of the Canadian Joint Operations Command (CJOC). The recommendation will be based on the review of current technologies, other nation's implementation of AM in the field, and the potential roadblocks that exist in the current system.

INTRODUCTION

2. There are several hindrances to getting the right part to the right place in the context of deployed operations. The first issue is supply chain management (SCM) in the CAF is a complicated process that involves multiple layers and organizations. These process issues can include finding the correct items, possibly spread across Canada, and getting them released for deployment. Needing to go and procure out of stock items, determining funding, sourcing suppliers, etc. are other challenges faced when using the CAF SCM systems. Next is the fact the strategic lines of communications (SLOCs) supporting current CAF deployments are lengthy, require dedicated sustainment planning, and are normally not designed to react to emergency requirements. Even when a part or tool is available and readily at hand in Canada, there is still a significant time delay in getting the item into the hands of the soldier in the field. This can be further complicated by host nation import regulations that can hold up critical items in bond for days or weeks on end. To mitigate these issues, support planners often attempt to plan to hold as many critical stores in theatre as possible, and build up stores of other items through regular sustainment. The problem with this practice is it is space, manpower, and cost intensive. It also not a viable solution for operations that do not have a set deployed operating base or support hub.

3. There exists emerging technology that can assist deployed operations reduce their dependence on SLOCs and the need to warehouse some critical stores on site. By exploiting the field of AM, support personnel can provide their commanders with the flexibility to manufacture needed components to meet mission needs. With this come the potential benefits of reducing footprints and overall mission costs. This paper will proceed by:

a. Reviewing current available technologies;
b. Exploring the use of AM in the field by military forces;
c. Providing some of the known downfalls and areas of concern that would apply to CAF integration;
d. Proposing a way forward to initiate the process to deploy AM capabilities;

DISCUSSION

4. The process of AM is a manufacturing technique whereby an object is created through the layering of materials. The process requires a virtual 3D model of the existing object or

prototype to be created. Then the model must be converted into a Computer Aided Design (CAD) file. Another program is then used to slice the file (creating individual 2D layers) before uploading to the printer. The printer reads then prints each slice of the 2D file to create the three dimensional objects. The current printing techniques that would be relevant for military use are:

a. Stereolithography (SLA): liquid photopolymers in a semi-liquid form are hardened layer by layer with an ultraviolet laser, building from the bottom up. It produces accurate and precise parts in a short amount of time.

b. Digital Light Processing (DLA): similar to SLA, it uses photopolymers to build up an object by layers. The main differences to SLA are it uses normal light to harden the material, and entire layers harden at one time versus a single point at a time with SLA. High resolution parts are created quickly with less waste using this method versus other methods.

c. Fused Deposition Modeling (FDM): this method relies on the extrusion of thermoplastic material to form the object. Final products are functional and durable, but require more post manufacturing finishing, usually done by hand.

d. Selective Laser Sintering (SLS): a layer of powder is layered down, after which a high power CO2 lasers fuse the powdered materials together. Another layer of powder is laid down and the process repeats, building the object from the bottom up. The materials used have expanded to include various metals, nylons, ceramics, and glass. End products require some finishing and because of the materials used are very durable.

e. Selective Laser Melting (SLM): very similar to SLS, but instead of only sintering the powder, it completely melts the powdered material. The strength of the materials and the ability to create complex, lightweight objects has seen this method adopted by the aerospace and medical industries.

f. Electron Beam Melting (EBM): similar to SLM it uses an electron beam in a vacuum versus a CO2 laser in an inert gas chamber. Currently used mainly for producing metal objects.[1]

5. The selection of which method(s) would be most beneficial for potential implementation in the CAF is dependent on many variables. Nicholas Meisel et al, in their paper submitted to the Journal of Manufacturing Technology Management, argue the main considerations should include machine constraints and objectives, parts constraints and objectives, material constraints and objectives, environmental constraints and objectives, and logistical constraints and objectives.[2] The paper is an excellent starting point for considerations needed to determine the

[1] Types of 3D Printers: Complete Guide - SLA, DLP, FDM, SLS, SLM, EBM, LOM, BJ, MJ Printing." 3D Insider. April 09, 2018. Accessed October 14, 2018. https://3dinsider.com/3d-printer-types/.

[2] Meisel, Nicholas A., 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): 902-908.

best technique for a given set of parameters. It provides a solid framework for designing a decision matrix for the selection process best suited for a given use. It is a must read if a decision to go forward with deployed AM technology were made.

6. Printing parts for military use, while a relatively new support concept for CJOC in a deployed context, is not a new endeavour for other environments within the CAF itself. The Royal Canadian Navy (RCN), at its Fleet Maintenance Facility Cape Scott in Halifax, N.S., has a team in place that is currently using AM to create parts and repair components for the aging Navy fleet.[3] While the capability is a shore based program, the lessons they learn could be applied to generate a ship based capability. The Canadian Special Operations Forces Command (CANSOFCOM) has been experimenting with 3D printing of various components and miniature capabilities. The testing includes determining the deployability of different printing equipment. The expertise and lessons learned from both of these organizations should be leveraged to assist in developing any future joint capability.

7. The different services in the United States are all developing deployed AM capabilities for many of the same reasons CJOC is exploring this concept. The United States Marine Corps (USMC) has advanced the furthest at implementing 3D printing into deployed operations. As of July 2017, they had a minimum of 40 printers deployed into theatres of operations. A key to their implementation plan was to first train individual marines how to operate the machines, and give them the skills to design and develop prototypes.[4] This eliminated the need to send additional specialists into the field with the equipment. Secondly, "unit commands were given broad authorization to use 3D printing to create repair parts for existing equipment."[5] This authorization is essential to allow for flexibility and speed of repairs. For CJOC to implement AM into deployed operations, a similar authorization would need to be obtained in order to cut the red tape involved in adapting, modifying, or repairing CAF equipment. Pre-approved processes signed off by technical authorities that are broad enough to be implemented in a decentralized manner in the field would be the most successful.

8. Traditionally, such processes would not be considered for the use on aircraft, given the low tolerances required for some parts. However, the United States Navy (USN) has flown aircraft with flight critical components produced by 3D printers and the United States Army has prototyped and flown unmanned aircraft using AM processes as well.[6] The United States Air Force is actively seeking to reduce costs and improve parts availability by implementing AM processes, as it has been proven to be a cost effective and efficient means of keeping aircraft out of the repair hangars and in the air.[7] By implementing adequate control mechanisms, one of the

[3] Canadian ForcesVideos. "The Innovators: 3D Printing Transforms the Royal Canadian Navy." YouTube. March 01, 2016. Accessed October 14, 2018. https://www.youtube.com/watch?v=PYwElA_ZHRo.

[4] Seck, Hope Hodge. "Marines Send 3D Printers to Combat Zone to Fix Gear Faster." Military.com. July 05, 2017. Accessed October 14, 2018. https://www.military.com/defensetech/2017/07/05/marines-send-3d-printers-combat-zone-fix-gear-faster.

[5] Ibid.

[6] Gager, Klinton R. "Just do it Yourself: Implementing 3D Printing in a Deployed Environment". Air University Maxwell Air Force Base United States 2017. Accessed October 14, 2018. http://www.dtic.mil/dtic/tr/fulltext/u2/1042209.pdf : 5.

[7] Ibid, p. 31-32

last bastions of resistance (coming from the Royal Canadian Air Force) to in house and deployed parts production can be overcome.

9. There are several areas of concern that must be reviewed and weighed before coming to a final decision to implement a deployable AM solution. Key among these areas is determining what items can and should be manufactured on site. It is not feasible to eliminate all deployed holdings and reduce the supply chain to simply restocking raw materials for the printers. Nor can many objects be efficiency recreated in theatre; ammunition, clothing stores, and shelters being just a few examples. There is an excellent paper titled "Selecting parts for additive manufacturing in service logistics"[8] written by a group of Dutch academics that provides a methodology to assist in the parts selection process. A detailed study would need to be undertaken on what items for each mission would be best suited for reproduction (whether they be deemed critical, difficult to source, or have prohibitive resupply timelines for instance). It would provide a solid starting point to planners to devise a system for deployed operations.

10. Another concern that needs to be addressed before implementing a deployable AM process is that of Intellectual Property (IP). There are three main areas to be resolved. First is determining if the CAF has or needs the permissions to reproduce an item. Second, does the CAF have the rights or permissions to use the digital files to be used by the printers? Lastly, are regulations in place for the protection of the IP rights for items (both digital files and actual objects) created by CAF personnel? While hobbyists and individuals who recreate items for home use are normally exempt from IP laws, the CAF would not be.[9] It would not be legal or ethical to send personnel and equipment into the field with the direction to just print anything needed. Obtaining the correct permissions if required becomes part of the parts selection process mentioned above.

11. Training and quality control will play a large role in the management of this capability, and may be a determining factor in who the end users are on actual deployments. Traditionally, the realm of manufacturing/repair in the CAF has fallen to either Material Technicians (Mat Techs) or civilian staff/contractors. The AM processes themselves are meant to be relatively simple compared to traditional manufacturing methods, but if the type of part being reproduced is critical to the operations of weapon systems, vehicles or aircraft, should specialists be in place to ensure proper finishes and tolerances are met? The risks involved need to be evaluated and this becomes a critical area to resolve before implementing deployed 3D printing capabilities on a large scale.

12. As is the case in other areas, the CAF has seen the use of AM technologies grow haphazardly among the different elements. It would be beneficial if at least one aspect of its use was centrally managed, that area being the use of the technology in deployed environments. As CJOC is the force employer of most deployed operations, and the owner of the SLOCs, it would be to the organization's benefit to take the lead in creating the framework and implementing the

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[8] Knofius, Nils, van der Heijden, Matthieu C, and W. H. M. Zijm. "Selecting Parts for Additive Manufacturing in Service Logistics." Journal of Manufacturing Technology Management 27, no. 7 (2016): 915-931.

[9] Malaty, Elsa, and Guilda Rostama, Dr. "*3D Printing and IP Law*." WIPO Magazine. February 2017. Accessed October 14, 2018. http://www.wipo.int/wipo_magazine/en/2017/01/article_0006.html.

initial capability. It could be argued that the manager of the process would be better suited residing within the Assistant Deputy Minister Materiel (ADM MAT) organization. This may be a valid argument for the development of the initial concept. However, as the concern raised by CJOC was specific to leveraging the capabilities for deployed operations, it seems obvious that the final control and overall oversight should remain within that chain of command.

13. There has already been much research done on the subject and there exist well developed systems in place with Allies that could be explored, and exploited. A dedicated project officer, or team, should take the next steps by taking the kernels of information put forward in this paper and commit further time researching the specific areas raised here. Time and resources allowing, it is not inconceivable that a proof of concept trial could be implemented to support a current CAF deployment in the near horizon. If successful, the data should support further implementation, and a change in the way deployed forces are supplied and maintained.

CONCLUSION

14. There can be no doubt that the emerging technologies revolving around 3D printing would be a force multiplier to CAF deployed operations. The ability to produce critical components in hours rather than waiting days to have them delivered from outside the theatre of operations cannot be undersold. The added savings of reduced warehousing requirements and transportation costs are also key drivers to going down this route. Granted, there is much work that needs to be done before any large scale capability could be fielded. Further research of which processes to implement, how to protect the CAF from IP infringement, the choosing of what to reproduce and who will operate the equipment is still needed.

RECOMMENDATION

15. It is recommended that a project be created within the CJOC COS Support organization to field a Deployable Additive Manufacturing Capability. At a minimum, one full time staff officer should be assigned to the project, and allocated sufficient resources to allow for the further research and development of the plan.

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