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3D PRINTING: AN INVESTMENT IN THE FUTURE OF THE RCAF

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AIM

1. The aim of this paper is to provide Commander 1 Canadian Air Division (Comd 1 CAD) with an examination of three-dimensional (3D) printing and the potential benefits it offers to the Royal Canadian Air Force (RCAF). This paper will concentrate on the advantages 3D printing can provide in the form of cost savings, improving the supply system and aircraft serviceability rates, and support to austere operations. It will discuss limitations of the technology and will conclude with recommendations as to what the RCAF needs to do to effectively implement a 3D printing program.

INTRODUCTION

2. With ageing aircraft fleets and serious deficiencies of spare parts within the RCAF supply chain, maintaining aircraft serviceability has become extremely difficult. Procuring parts for many of these aircraft is challenging as many are no longer manufactured. This leads to long wait times and costly contracts when essential spare parts need to be privately produced, effectively prohibiting RCAF aircraft from conducting essential flying operations.

3. Deployed flying operations rely upon spare parts being available when needed so that aircraft are mission-ready at all times. Limited spares within the RCAF supply system result in priority being placed on operationally deployed aircraft, often leaving no spare parts in Canada for the remainder of the affected fleet. In other cases, insufficient spare parts available for in-theatre assets result in extended periods of deployed unserviceability when deployed maintainers must wait for ordered parts to be delivered. These delays are frequently exacerbated by hold-ups within customs at the end destination. Even domestically, Canada's multi-tiered supply system results in parts being centrally located in warehouses situated at vast distances from flying wings: this necessitates days of waiting for the required spare parts to be shipped and delivered.

4. 3D printing technology offers a cost effective solution to many of the RCAF's parts procurement challenges. This paper will focus on the cost and time saving benefits of 3D printing to illustrate why it is essential that the RCAF pursue this technology immediately. After identifying the benefits and limitations of 3D printing to the RCAF, recommendations for its implementation will be provided.

DISCUSSION

5. Additive Manufacturing (AM), or 3D printing, is a technology that is now actively utilized by leaders in the military aerospace industry For example, Boeing and Lockheed have been utilizing 3D-printed parts in some of their aircraft since 2013.[1] Foreign militaries are also utilizing 3D-printed parts in some of their aircraft: the Royal Air Force (RAF) has printed and

[1] Michael C. Horowitz, "Coming next in military tech," Bulletin of the Atomic Scientists 70, no. 1 (November 2015): 58, https://doi.org/10.1177/0096340213516743.

flown parts for their Panavia Tornado GR.4 strike aircraft,[2] the United States Navy (USN) has printed valves for its Boeing T-45 Goshawk aircraft,[3] and the Royal Australian Air Force (RAAF) has utilized AM to repair Boeing F/A-18 Hornet fighter aircraft.[4] While many of our allies have embraced the benefits offered by this technology, the RCAF has yet to pursue it.

6. 3D printing functions in a manner similar to inkjet printers in that it utilizes a computer aided drafting (CAD) file of the object being created to instruct the printer where to deposit materials. The major difference lies in the fact that, rather than containing ink, the print heads on 3D printers normally contain a material that is heated to just past its melting point so that it solidifies when 'printed.' 3D printers make multiple passes across the object they are creating, slowly building a three-dimensional object.[5] This method of manufacturing differs from standard subtractive manufacturing methods which start with a large amount of raw material and slowly cut away from it in order to shape it into the desired object or mold.

7. This technology is not new to the Canadian Armed Forces (CAF). The Royal Canadian Navy (RCN) has been working with a laser additive manufacturing (LAM) system for more than three years out of Fleet Maintenance Facility Cape Scott (FMF CS)[6] and recently deployed its first ship-borne 3D printer for trials.[7] Clearly, a baseline level of 3D printing knowledge already exists within the CAF, however the RCAF has yet to make use of it.

8. While AM technology and its associated product quality continue to advance, it has not yet reached the level where it can replace traditional manufacturing methods due to the complexities associated with parts comprised of a variety of materials and the slow speed at which 3D printers operate. However, the potential it offers for quickly generating one-of, single-medium objects is phenomenal. For example, the CP140M project to test iPads for cockpit use has been severely delayed as a result of a need for a mounting bracket. These brackets could easily have been designed and produced using a 3D printer, with the required bracket being constructed in weeks rather than months. Other future uses include research currently ongoing by the US Army wherein the possibility of printing uniforms is being explored.[8] Considering the fact that the RCAF has been unable to outfit its airmen and women in flightsuits for several years, an ability for the supply system to print made-to-measure uniforms would undoubtedly ensure that personnel were always clothed professionally.

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[2] Michael J. Gething, "3-D parts fly for first time on Tornado," *Jane's Defence Weekly* 51, no. 7 (January 20-14), https://search-proquest-com.cfc.idm.oclc.org/docview/1476249237?accountid=9867.

[3] Michael James Fabey, "3-D printed parts help keep USN T-45 trainers aloft," *Jane's Defence Weekly* (12 July 2017), www.janes.com/article/72257.

[4] Jon Grevatt, "Australia advances 3D printing to support military aircraft," *Jane's Defence Industry* 34, no. 6 (June 2017), https://janes.ihs.com/DefenceIndustry/DisplayFile/.

[5] Erica Neely, "The Risks of Revolution: Ethical Dilemmas in 3D Printing from a US Perspective," *Science and Engineering Ethics* 22, no. 5 (October 2016): 1286.

[6] "3D Printing Transforms the RCN," *The Maple Leaf* 19, no. 1 (January 2016): 10.

[7] Cdr James Allen, "Maritime Functions and Capabilities" (lecture, Canadian Forces College, Toronto, ON, 28 September 2018), with permission.

[8] *5 Ways U.S. Army Uses 3D Printing*, Chatham: Newstex, 2014, https://search-proquest-com.cfc.idm.oclc.org/docview/1635303913?accountid=9867.

Cost Savings

9. A major advantage of utilizing 3D printing lies in the cost savings that the technology delivers. The cost and associated time delay of procuring parts that are no longer built by aircraft suppliers can be exorbitant and the RCAF supply system constantly struggles to fit some of its fleets with required spare parts. This compels the RCAF to either engage in the costly endeavor of funding the manufacturing of a new batch of these spares, or to cannibalize other airframes, including those located at museums, for their parts.[9] 3D printing offers the possibility of having a constant, on-demand ability to print required spares. Rather than creating contracts that require the RCAF to purchase parts from suppliers, 3D printing would allow the RCAF to instead simply purchase the CAD files of individual aircraft parts. This would enable maintainers to print parts when required and would ensure that any printable part is never more than a few hours of printing time away from being available.

10. Within the supply chain, 80% of the parts that are needed most frequently make up the majority of aircraft parts demands. However, this accounts for only "20% of the supply chain expenditure in terms of holding inventory and moving materials."[10] This means that most of the costs within the supply chain are incurred by the cost of the less frequently needed parts, so suppliers frequently subsidize the cost of storing these parts with profits generated from over-charging for the more frequently needed parts.[11] Because subtractive manufacturing methods require parts to be produced in large batch sizes in order to maximize economies of scale, large batch sizes of less frequently needed parts are often produced and then stored.[12] Combining these factors results in needlessly high parts costs paid by the RCAF to contracted suppliers. If the RCAF were to instead negotiate contracts that allow the RCAF to utilize 3D printing to create these parts on demand, the life cycle costs of RCAF aircraft would be significantly reduced.

11. 3D printing has the potential to enable maintainers to print small components of larger parts assemblies rather than having to replace the entire apparatus at a significant cost. For example, the United States Marine Corps (USMC) was able to 3D print a part for the landing gear door of an F-35 stealth fighter. The damaged part was not available for purchase individually, meaning that a new landing gear door costing $70 000 USD would have been required. Using 3D printing, the necessary part was manufactured for a cost of approximately nine cents.[13] Similarly, the United States Navy (USN) used 3D printing to produce electric motor cooling fans for a cost of $1.39 each compared to their open purchase price of $375.00.[14] While these costs do not take into consideration the cost of the 3D printing equipment or training

[9] Lee Berthiaume, "Royal Canadian Air Force raided museum for search-and-rescue airplane parts," *Ottawa Citizen*, 15 September 2014.

[10] Liang Hou, Samuel H. Huang, Peng Liu, and Abhiram Mokasdar, "The impact of additive manufacturing in the aircraft spare parts supply chain: supply chain operation reference (scor) model based analysis," *Production & Planning Control* 25, nos. 13-14, 1170.

[11] *Ibid.*

[12] *Ibid*.

[13] Umair Iftikhar, "U.S. Marines 3D Print F-35 Part to Save $70,000," last accessed 11 October 2018, https://3dprintingindustry.com/news/u-s-marines-3d-print-f-35-part-to-save-70000-138484/.

[14] John Joyce, "Navy and Marine Corps Showcase 3D Printing Innovations and Impact at Pentagon Expo," *CHIPS Magazine* (Jan-Mar 2017), http://www.doncio.navy.mil/CHIPS/ ArticleDetails.aspx?ID=8808.

required to design the CAD file from which the part was printed, they do clearly demonstrate the potential for significant cost savings for the military.

12. While 3D printing can reduce the material costs of manufacturing items by up to 90%, it also has the potential to reduce energy use by up to 50% compared to that used during subtractive manufacturing.[15] This represents significant savings to RCAF maintainers who are often required to tool their own parts, and can be built into life cycle contracts for new aircraft in order to reduce overall life cycle costs.[16] Equally as important, 3D printing allows complex parts that cannot be subtractively manufactured as one piece to be constructed as single objects, creating more durable, lighter, sustainable parts for aircraft that, as a result of their simplified structures, are less likely to break.[17]

13. Finally, the RCAF (and, indeed, the CAF as a whole) stands to realize tremendous savings in Yearly Flying Rate (YFR), fuel, and person-hours by deploying 3D printers with the capability of printing basic tools and spare parts to theatres of operation. By being able to print required spares on demand, the cost of transporting urgently needed parts would be eliminated.[18] The RCAF operational tempo could be decreased as Mobile Repair Party (MRP) flights would be required less often and, most importantly, the disruptions in operations and exercises resulting from unserviceable aircraft would diminish resulting in a more effective, globally relevant flying force.

Supply Chain and Serviceability Improvements

14. The RCAF doctrine on sustainment lists nine critical principles. All of these principles directly affect the delivery of air power and all could be improved upon in order to render the RCAF a more effective, meaningful force. The capabilities and benefits associated with 3D printing meet six of these principles: economy, flexibility, simplicity, self-sufficiency, responsiveness, and survivability.[19]

15. Storage of spares takes up space and is costly. 3D printing has the potential to reduce the need for parts inventory.[20] Both domestically and internationally, space tends to be at a premium and it has become undesirable to store an excess of parts 'in case' they might be needed. When deployed, air detachments are often given a small footprint from which to operate and simply cannot transport and store every part that might be required for an aircraft. 3D printing offers significant benefits with regards to space savings as it enables a variety of parts and tools to be printed when required as opposed to waiting for the steps of the supply chain process to be

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[15] *The Maple Leaf*, 10.

[16] *Products in the News: Fonon at Cutting-Edge of 3D Military Printing*. Chatham: Newstex, 2014: 1, https://search-proquest-com.cfc.idm.oclc.org/docview/1642351389?accountid=9867.

[17] *Ibid.*

[18] *Ibid*.

[19] Department of National Defence, B-GA-402-003/FP-001, *Royal Canadian Air Force Doctrine: Sustainment*, (Ottawa: DND Canada, 2017), 2-2. Note: the remaining three principles are foresight, cooperation, and visibility.

[20] Liang Hou, Samuel H. Huang, Peng Liu, and Abhiram Mokasdar, "The impact of additive manufacturing in the aircraft spare parts supply chain: supply chain operation reference (scor) model based analysis," *Production & Planning Control* 25, nos. 13-14, 1170.

carried out.[21] This would remove both the space requirement of storage for an abundance of parts, with the need for space instead being simply for generic raw printing materials and the printers themselves, and the expense of transporting parts to and from deployed bases. Considering the frequency with which ordered parts arrive unserviceable,[22] a solution such as this offers huge advantages to sustaining flying operations and eliminating needless shipping costs.

16. The time savings of being able to locally print parts is also fundamental to improving RCAF-wide aircraft serviceability. With the RCAF supply system being divided into four levels of support, only some parts are held at the Wing.[23] Most others are located at a centrally-based supply depot and the wait time for wings to receive needed parts can be several days, often grounding aircraft for that wait time. Being able to locally print parts would both eliminate the need for those parts to be stored in warehouses and would enable more rapid aircraft repairs, representing a much greater economy and responsiveness for RCAF maintenance. The USN demonstrated the time savings that can be achieved by 3D printing when an AV-8B Harrier experienced a hard landing onboard a USN amphibious assault ship, causing damage that was given an estimate of two to three weeks to fix. Using a 3D printer to manufacture the required tools, the repair was carried out in just four days and for a significantly lesser cost.[24]

17. Strong, Secure, Engaged (SSE), Canada's Defence Policy, lists reducing the military's carbon footprint and greenhouse gas emissions as a priority.[25] The ability to print locally would result in a lessened environmental impact as the associated transportation costs of shipping objects would be reduced.[26] Furthermore, 3D printing conserves raw materials in comparison to subtractive manufacturing because it utilizes only the material needed to construct an object.[27]

18. SSE states that the RCAF "will need to sustain existing capacity and continue to acquire modern aerospace capabilities that have an operational advantage."[28] It also asserts that the government will "(r)ecapitalize or life-extend existing capabilities in advance of the arrival of next generation platforms" and "(s)ustain domestic search and rescue capability, to include life extension of existing systems."[29] 3D printing offers a practical, functional solution to sustaining Canada's existing aircraft fleets into their life extensions.

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[21] Sean R. Walsh, "3D printing – enhancing expeditionary logistics," *Marine Corps Gazette* 99, no. 3 (March 2015): 67.

[22] Anecdotal evidence from the author's deployed experience over the past five years with the CP140 fleet.

[23] *Ibid.*, 1-4.

[24] Jon Rosamond, "3-D Printing promises radical change for equipment procurement and support, says NAVAIR," *Jane's Navy International* 119, no. 7 (September 2014), https://janes.ihs.com/NavyInternational/Display File/jni76459?edition=2014.

[25] Department of National Defence. *Strong, Secure, Engaged - Canada's Defence Policy.* 2017, 16.

[26] Neely, 1295.

[27] *Ibid.*

[28] *Strong, Secure, Engaged*, 39.

[29] *Ibid.*, 39.

Support to Austere Operations

19. Austere operations, whether domestic or international, pose challenging demands upon the supply chain. With ever-increasing focus being placed upon the Canadian Arctic and an omnipresent demand for air power in Canada's north, the potential 3D printing offers to solving the problems associated with supply chain challenges in these locations must not be overlooked. This potential could also be realized at forward-deployed locations such as Erbil, Iraq where Canada is currently operating CH-146 Griffon helicopters. Rather than constantly reaching back to Canada and incurring danger to friendly resupply aircraft to transport needed parts, the ability to print these parts on demand would greatly improve the Griffon detachments self-sustainability.

Limitations

20. The adoption of any new technology comes with an array of challenges, and 3D printing is no different. Of primary importance is the fact that the RCAF will need to hire or train CAD experts who will be responsible for creating the required printing designs and maintaining the printing and computer equipment. The legal aspect of self-manufacturing parts will also need to be investigated in order to ensure that any printed parts are printed with the original manufacturer's concurrence. Furthermore, airworthiness of printed parts needs to be investigated and appropriate limitations published, however knowledge gained by industry and allied air forces can be leveraged to assist in determining what aircraft parts can safely be printed and utilized.

21. It also must be noted that 3D printing does not offer the solution to all supply issues. Slow printing speed, complexity of designs, and the requirement for raw printing materials are all factors that are currently limiting AM capabilities.[30] That said, even at its present state, the technology offers significant benefits to the RCAF and should not be discounted because it is not yet fully mature.

CONCLUSION

22. 3D printing is an essential future capability that the RCAF should implement immediately. It offers significant cost savings to the life cycle of aircraft, an ability to rapidly develop parts needed to test new equipment, environmental benefits and, most importantly, an ability to improve Canada's delivery of air power by lessening aircraft unserviceability timelines as maintainers wait for spare parts to be shipped. Investing in the future is a requirement if the RCAF is to remain viable amongst our allies, and utilizing 3D printing technology to improve aircraft serviceability while incurring life cycle and supply chain cost savings is a simple step towards realizing that investment.

RECOMMENDATIONS

22. The following actions are recommended with respect to the adoption and implementation of 3D printing by the RCAF:

[30] Horowitz, 59.

a. Establish a working group to determine air worthiness requirements with respect to 3D-printed parts, working with the aviation industry and allied air forces;

b. Establish a connection with the RCN in order to leverage their existing knowledge regarding 3D printing and its implementation within the CAF;

c. Conduct RCAF-wide data collection to determine the frequency and commonality of aircraft parts unserviceabilities, then analyze this data to determine where serviceability could be improved by utilizing 3D-printed parts; and

d. Liaise with allied militaries such as the United Kingdom, the United States, and Australia to leverage their knowledge of uses for 3D printing in aviation.

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