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Expanding Additive Manufacturing Beyond the Sustainment Framework to Evolve Canadian Special Operations Force Command's Competitive Advantage

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AIM

1. To examine the benefits and limitations of deployed additive manufacturing (AM) capabilities as an enabling factor to realize Canadian Special Operations Force Command's (CANSOFCOM) Strategic Vision and to "continue[ly] contribute to the achievement of overall competitive advantage" as the future environment expands further into the grey space of conflict.[1]

INTRODUCTION

2. The CANSOFCOM's Strategic Vision encapsulates an inherent operational niche within the grey space of conflict for Special Operations professionals to be empowered and enabled to "advise, detect, and lead in the detection, pursuit and defeat of asymmetric threats to Canada across all domains".[2] Internationally, Canada's adversaries (state and non-state actors) operate in the grey space operational niche to "rewire and restructure the global economy […] by unhinging traditionally monopolized weapons: information, capital, and technology to propagate a more disparately distributed narrative and to undermine fundamental democratic institutions".[3] Furthermore, the technological advancements within the last century have profoundly interconnected individuals to an infinite wealth of information and data to promote their ideologies and agendas. Therefore, the functional grey space expands CANSOFCOM's niche to include non-state actors (individuals and organizations) within Canada's domestic boundaries.[4]

3. In the same vein, for CANSOFCOM to strategically excel in the grey space, CANSOFCOM's "playing field" demands an alignment and examination of its current systems to "illuminate" the battlespace and counter asymmetric threats enrooted with obstacles to cloud state and non-state actor involvement. Disruptive technologies, such as additive manufacturing (AM), offer CANSOFCOM opportunities to balance the "playing field" to provide an over-horizon operational function "Sense" to illuminate the battlespace in order to enable a relevant and credible counter to an asymmetric threat at home and abroad.

4. Significant research conducted in the past decade has credibly demonstrated the value of deploying AM to sustain conventional military operations. Additive manufacturing, or three-dimension (3D) printing, enables conventional military forces to revolutionize supply chain management and sustainment modelling to fabricate "low-volume, customized, and intricate"

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[1] Department of National Defence, *Beyond the Horizon –A Strategy for Canada's Special Operations Forces in an Evolving Security Enivornment*, 2020, 34.
[2] *Ibid.,14.*
[3] John Raine, *War or peace? Understanding the grey zone*, 03 April 2019. www.iiss.org/blogs/analysis/2019/04/understanding-the-grey-zone#:~:text=It%20is%20the%20'grey%20zone'%20where%20hybrid%20or,steadily%20growing%20number%20of%20players%2C%20capabilities%20and%20agendas. Accessed on: 29 December 2021.
[4] Department of National Defence, *Beyond the Horizon –A Strategy for Canada's Special Operations Forces in an Evolving Security Enivornment*, 2020, 13.

spare parts without requisitioning from depots or procuring from the industry.[5] However, from the CANSOFCOM perspective, three factors are presented herein that negatively impact an optimal AM sustainment solution to enable SOF operations.

5. The first limitation or necessary consideration, and at the institutional level, is the ethical implications of AM. Additive manufacturing applications' profound (unlimited) availability to potentially leverage operational success may also lead to ethical dilemmas. Mattox suggests that AM, as a "dual-use technology, [there is] possibility of the rapid and uncontrolled replication of highly sophisticated tools of violent action".[6] Similarly to the broad spectrum of SOF operations and military ethos, the introduction of additive manufacturing opens opportunities to question and determine whether ethics are part of the equation when deploying disruptive technologies, such as AM, in the field. Furthermore, AM questions whether there are sufficient internal controls and governance to ethically determine an acceptable process to manufacture highly customized equipment and weapons while respecting intellectual property (IP) rights. The final ethical consideration examines whether there are instances when AM products should remain unmanufactured (i.e. additive manufactured bullets, weaponized drones), or does the circumstances (i.e. life and death situation of Canadian Armed Forces member) dictate and allow AM products, such as weapons, to protect the safety and security of CAF members and equipment?

6. The abundance of product possibilities for AM leads to its second limitation. Additive manufacturing lacks standardization and quality in fabricating products. As a result, Ford suggests that the final product may not conform to the safety, reliability, and performance specifications.[7] Furthermore, given that the role of SOF operations is to remain innovative while versatile, Saunders' research demonstrated that SOF component customization [to fit the mission] might not have the tensile strength to endure under austere conditions.[8] Finally, an additive manufactured product fabricated without the correct standards and materials may inherently jeopardize SOF personnel safety and, ultimately, the mission. This consideration counter CANSOFCOM's centre of gravity grounded on their competitive advantage: their personnel.[9]

7. Further countering CANSOFCOM's operational philosophy is illustrated in Figure 1. The third factor, and more importantly, the expansive footprint required to deploy AM equipment to deliver the "sustain" function in the field, is an impractical solution for SOF operations due to time, size, weight, and power generation requirements. Therefore, the AM equipment and

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[5] Sharon L.N. Ford, *Additive Manufacturing Technology: Potential Implications for U.S. Manufacturing Competitiveness*, United States International Trade Commission, Journal of International Commerce and Economics, September 2014, 12. ww.usitc.gov/journals/Vol_VI_Article4_Additive_Manufacturing_Technology.pdf. Accessed on: Accessed on: 29 December 2021.

[6] John Mattox, *Additive Manufacturing and Its Implications for Military Ethics*, Journal of Military Ethics, 12(3), 2013, 225.

[7] Sharon L.N. Ford, *Additive Manufacturing Technology: Potential Implications for U.S. Manufacturing Competitiveness*, United States International Trade Commission, Journal of International Commerce and Economics, September 2014, 12.

[8] Lisa Saunders, *Implications of Additive Manufacturing Deployed at the Tactical Edge*, The Defense Acquisition University, 15 April 2015, 2. www.dau.edu/training/career-development/sscf/Documents/5.%20SRP%20FINAL_L%20Sanders_15%20Apr%202015--Edited%20and%20Corrected%20Final.pdf. Accessed on 30 December 2021.

[9] Department of National Defence, *Beyond the Horizon –A Strategy for Canada's Special Operations Forces in an Evolving Security Enivornment*, 2020, 29.

requirement counters CANSOFCOM's ideology to effectively operate remotely while discretely employing small units to achieve mission effects. [10]

Figure 1: Australian Army Deploys Additive Manufacturing Equipment

Source: Sarah Saunders, *WarpSPEE3D Metal 3D Printer Successfully Deployed by Australian Army in Field Exercise*, 3Dprint.com The Voice of 3D Printing/Additive Manufacturing, 29 June 2020. www.3dprint.com/269413/warpspee3d-metal-3d-printer-successfully-deployed-by-australian-army-in-field-exercise/. Accessed on: 29 December 2021.

8. Alternatively, as highlighted in "*Beyond the Horizon"*, CANSOFCOM aims to shift the paradigm "in the pursuit of operational excellence [through] high-value strategic, and innovative options"[11], in where AM is a viable solution to enhance and augment CANSOFCOM's agility. This paradigm shifts the focus from a Sustain function to embracing value-added benefits by harnessing AM capabilities to enhance CANSOFCOM's Sense function through inexpensive disposable drones and, or everyday products (i.e. mobile phones) precisely customized to enable operational success.

DISCUSSION

9. The Canadian Armed Forces (CAF) operational function of Sense directly links to the CANSOFCOM's "*Beyond the Horizon"* philosophical approach to facilitate oversight and scanning of future asymmetric threats by gathering data from sensors to "inform the collective defence and security whole of government response".[12] Furthermore, Baylay and Kopac suggest additional tactical advantages where SOF leverage AM to construct sensors and remote autonomous aerial drone (RAAD) customized to augment the Sense function to a specific mission set vice constricted to what the industry offers commercially at home or aboard.[13] Since AM, or three-dimensional printing (3D printing), creates products by layering-process with a machine based on digitized software and building material (i.e. plastic, wood, powder, and

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[10] *Ibid., 29.*

[11] *Ibid., 29.*

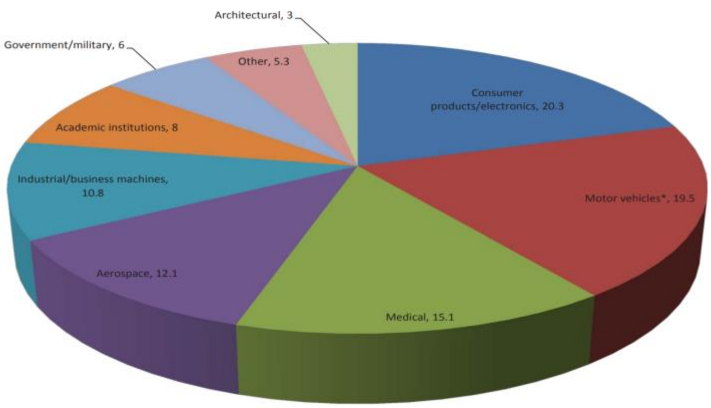
[12] Christopher Bayley and Michael Kopac, The Implications of Additive Manufacturing on Canadian Armed Forces Operational Functions, *Canadian Military Journal* 18, no. 3 (Summer 2018), 51. http://www.journal.forces.gc.ca/vol18/no3/PDF/CMJ183Ep47.pdf. Accessed on 29 December 2021.

[13] *Ibid., 52.*

metal), SOF personnel may customize the final product to adapt to a unique situation.[14] Therefore, AM offers flexibility to customize, design, and adapt as the situation evolves during the mission.

10. Additive manufacturing is a disruptive technology that continues to gain traction with the general public and commercial industries. Figure 2 illustrates that AM is transforming industries (i.e. automotive, aerospace, medical) and the monetary impact on these industries' revenues further incentives industries to adopt AM processes to streamline supply chain and production efficiencies. In addition, the data presented in Figure 2 represent less than 1 percent of the industry; however, the United States Department of Commerce concluded an "abundant potential for growth".[15]

Figure 2: Industries Served and Approximate Revenues (by Percent) for Additive Manufacturing (2011)

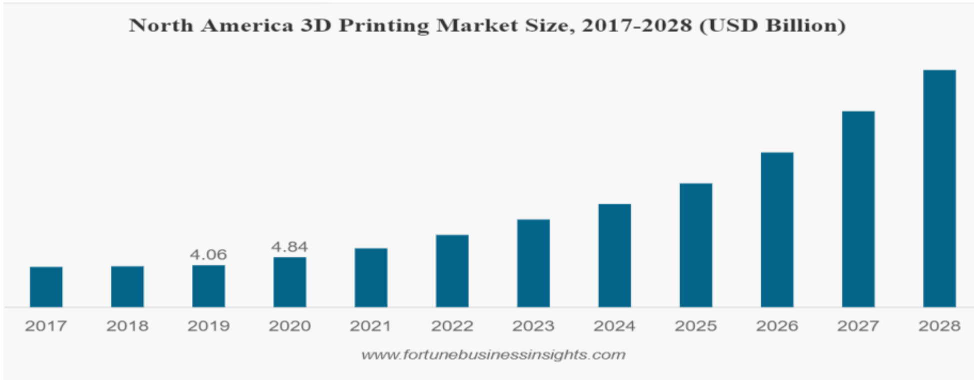


Source: Sharon L.N. Ford, *Additive Manufacturing Technology: Potential Implications for U.S. Manufacturing Competitiveness*, United States International Trade Commission, Journal of International Commerce and Economics, September 2014, 12.

11. Furthermore, to illustrate the point of growth, Figure 3 demonstrates that the 3D printing market size is trending upward from $15.26 billion (2021) to $68.71 billion (2029).[16]

Figure 3: North America 3D Printing Market Size, 2017-2028 (USD Billion)

[14] 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, Vol.27, No.7, 2016, 899.
[15] Sharon L.N. Ford, *Additive Manufacturing Technology: Potential Implications for U.S. Manufacturing Competitiveness*, United States International Trade Commission, Journal of International Commerce and Economics, September 2014, 7.
[16] Fortune Business Inisights, "Hardware & Software IT Services / 3D Printing Market", www.fortunebusinessinsights.com/industry-reports/3d-printing-market-101902. Accessed on 29 December 2021.



Source: Fortune Business Insights, "Hardware & Software IT Services / 3D Printing Market", www.fortunebusinessinsights.com/industry-reports/3d-printing-market-101902. Accessed on 29 December 2021.

12. Consumer demand and availability to purchase portable 3D printers fuels this positive trend because one could purchase a portable 3D printer starting at $200 CDN from Amazon.[17] Furthermore, the ease of accessibility and price point enables anyone and everyone who wishes to purchase a non-industrial 3D printer. Furthermore, greater computing power dovetailing a low learning curve have made the 3D printer an attractive choice for consumers and schools.[18] The price point and ease of accessibility make AM possible for SOF operations to build and fabricate products to suit the mission-set while remaining within the financial delegated authorities to procure 3D printers without compromising discretion and operational footprint. As technology continues to refine the 3D printer, the AM limitations initially proposed (i.e. time, size, weight, and power generation considerations) will further be negated, only to improve supportability and competitive advantage to enable SOF operations.

13. Moreover, Lele adds that AM improves inventory and warehouse management efficiencies from a supply chain management perspective because products are manufactured based on customer demands.[19] However, unlike the current field-testing of AM equipment at the conventional forces level, portable 3D printers sold on Amazon offer significant benefits that align to the SOF mantra and strategies highlighted in "*Beyond Horizons*": agility and flexibility to mission needs, and relationship building and collaboration with local partners (i.e. industry, and Whole of Canada approach) to "balance the playing field". [20]

14. Part of balancing the playing field means SOF units at the tactical level often resort to improvision, and, as Ford's research suggests that SOF units often leverage local businesses to manufacture and procure limited use items (i.e. local mobile phones, locally manufactured items to reduce military visibility, UAVs).[21] In addition, Ford offers practical examples for AM integration in SOF operations, such as an additive manufactured mobile phone deployed in-situ

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[17] www.amazon.com/s?k=3-d+printer&crid=8JHQLAW7D10W&sprefix=3-d+printer%2Caps%2C97&ref=nb_sb_noss_2. Accessed on 29 December 2021.
[18] A.S, Brown, *By the numbers: A big forecast for 3-D printers,* Mechanical Engineering, 136(2), 2015, 28.
[19] Lele, Ajey, *Disruptive Technologies for the Militaries and Security*, Singapore: Springer Singapore Pte. Limited, 2019.
[20] Department of National Defence, *Beyond the Horizon –A Strategy for Canada's Special Operations Forces in an Evolving Security Enivornment*, 2020, 13.
[21] Sharon L.N. Ford, *Additive Manufacturing Technology: Potential Implications for U.S. Manufacturing Competitiveness*, United States International Trade Commission, Journal of International Commerce and Economics, September 2014, 2.

to add a security layer, to the actual unit's specifications, within their communications plan.[22] Furthermore, this example illustrates AM as an integral component to the CAF's operational function "Shield".

15. Additive manufacturing is a force multiplier to the tactical SOF units deployed, enabling every element of the CAF operational functions. In particular, AM enables SOF units to leverage AM to enhance the Sense function while deployed in remote and austere locations. For example, dovetailing an affordable 3D printer and Amazon's global supply chain, CANSOFCOM units can order and receive portable 3D printers to manufacture customized drones for specific surveillance and reconnaissance objectives anywhere. A simple search online will reveal an abundance of drone designs that include digital cameras for anyone to locally produce with a portable 3-D printer (Figure 4) at a fraction of the cost of buying a drone from industry or unknown sources.

Figure 4: Amateur Made Drones from 3D Printers

Source: www.blog.layertrove.com/wp-content/uploads/2016/08/3D-Printed-Drone-3D-Printed-Quadcopter.jpg. Accessed on 29 December 2021.

16. Besides the financial benefits, as illustrated in Figure 4, an AM drone or sensor offers an immediate "over the horizon" system to mitigate risks and minimize ambiguity during SOF's personnel decision-action cycle operations within the grey space. Drones deployed increase data collection to develop credible trends by providing "high quality, more consistent, and repeatable data sets".[23] Furthermore, the development of trends based on real-time feedback from the drones enable autonomous SOF personnel, as CANSOFCOM's competitive advantage, to be "empowered to [adapt and to] make self-informed decisions […] vital to CANSOFCOM's decision-action cycle".[24] Additive manufactured drones add clarity to the already clouded grey operational sphere by providing a customized track and real-time video feed to depict the ground and evolving situation accurately.

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[22] *Ibid., 2.*
[23] Maghazei, Omid and Torbjørn Netland, *Drones in Manufacturing: Exploring Opportunities for Research and Practice*, Journal of Manufacturing Technology Management, Vol. 31, no. 6, 2020, 1247.
[24] Department of National Defence, *Beyond the Horizon –A Strategy for Canada's Special Operations Forces in an Evolving Security Enivornmtnt*, 2020, 28.

17. Additive manufacturing allows for infinite possibilities to customize drones to unique mission sets that CANSOFCOM will undoubtedly face in the future. Customizations conducted on a portable 3D printer eliminate the research and development capital costs because the blueprints are open-source designs on the Internet (Figure 4). In addition, amateur 3D printers produce lessons learned of their product online (i.e. youtube.com). Amateur developers have encumbered the costs associated with risks, tests, and development with their work documented and packaged into episodes for anyone to review online.[25] Since the reviews and lessons learned are readily available, SOF personnel can quickly access the information and determine which drone model best suits the mission.

18. Moreover, additive manufacturing offers adaptability to quickly fabricate interchangeable parts and replacement parts without leveraging third and fourth support lines. Portable 3D printers can reprint the replacement part to ensure serviceability if the drone is damaged. In addition, as the mission evolves, SOF personnel can leverage AM to fabricate a part more suited to the conditions. For example, if the drone's payload was insufficient for the camera, SOF personnel could re-scale the 3D printer to fabricate a larger drone version to accommodate the heavier camera (Figure 4, the middle graphic illustrates three similar drones of various sizes). Furthermore, part reproduction at the tactical level curtails shipping and delivery expenses (i.e. depot (Canada) to the customer or supplier (Canada) to customer) while ensuring a timely throughput of the part to the end-user. As a result, SOF personnel can adapt and prolong their surveillance presence or Sense operations in the region to minimize delay and wait time at the tactical level.

19. Although AM offers significant benefits to enable the Sense function, such as customization and adaptability, several considerations and limitations within the AM domain still require further in-depth discussion prior to implementation. The first limitation is the lack of standardization of building material and final product quality. Ford's research supports and highlights that "developing standard is critical […] foundation for creating products" to perform with repeatable results (i.e. performance, quality, reliability) and software compatibility.[26] Standardization will ensure that the drone produced through portable 3D printers will adhere to expected operational results with minimal risk (i.e. disastrous due to explosion or system failure) to personnel or the mission.

20. In addition, standardization of product development highlights the second limitation concerning ethical employment of AM and IP rights and control. Intellectual property control concerning the "authenticity of the products made using AM" since most ad-hoc designs are available online, and its designs are "surreptitiously modif[ied] with the intent of decreasing

[25] A video illustrating a build highlighting a low-cost drone (under $99) (www.youtube.com/watch?v=GFNGUDT_9_c)

[26] Sharon L.N. Ford, *Additive Manufacturing Technology: Potential Implications for U.S. Manufacturing Competitiveness*, United States International Trade Commission, Journal of International Commerce and Economics, September 2014, 20.

reliability and increasing harm to the end-user (i.e. SOF personnel).[27] Furthermore, CANSOFCOM must remain respectful of the IP rights of commercially patented drone designs. However, open-source designs add complexity to the grey space dilemma that involves ethical considerations where copyright laws are different from North American standards. For example, would operations outside North America justify leveraging AM functionality to fabricate a drone design or weapon to accomplish the mission expediently?

[27] Christopher Bayley and Michael Kopac, The Implications of Additive Manufacturing on Canadian Armed Forces Operational Functions, *Canadian Military Journal* 18, no. 3, Summer 2018, 53. http://www.journal.forces.gc.ca/vol18/no3/PDF/CMJ183Ep47.pdf.

CONCLUSION

21. Additive manufacturing in the context of industry practice highlights benefits that will add value to enhancing CANSOFCOM's operational function Sense. First, these customized drones collect data to build trends and information at a fraction of the cost. As a result, the data and trends minimize the ambiguity of the tactical picture on the ground. Second, the rich data correlates to SOF personnel at the tactical level to have the "right information, at the right time" to make autonomous and rapid decisions to achieve the mission effect. However, AM's potential dives to ethical considerations regarding function and employment in a military context. As a result, there needs to be institutional discussion and guidance on the ethical deployment of AM. At this time, AM offers significant potential to streamline sustainment and sense operations, but the "sweeping technology […] could change war [and] ethics fundamentally [because] every AM problem may become a military ethics problem".[28]

RECOMMENDATION

22. There needs to be a deliberate approach to set the right conditions before fully deploying AM capabilities as an enabling factor to realize CANSOFCOM's Strategic Vision. The fundamental step begins with establishing a working group to discuss and develop an ethics and standards baseline and guideline concerning AM. Example discussion points should focus on IP rights and control, and whether situational circumstances justify ethical dilemmas concerning AM and the deployment of drones or drone weaponization. The ethics guidelines will enable CANSOFCOM to leverage AM capabilities while remaining transparent and fully aligned to the values outlined in "Beyond the Horizon" and the CAF's Defence Ethics Program.

23. The second aim is to establish production and software standards concerning AM fabricated drones or other one time use products to support CANSOFCOM missions. The objective is to ensure that the products are repeatable with similar results (i.e. performance) in the field. Finally, establishing an ethics and standards foundation will pave CANSOFCOM's next bound in deploying AM capabilities to enhance the operational function Sense in support of the Government of Canada's mandate.

[28] John Mattox, *Additive Manufacturing and Its Implications for Military Ethics*, Journal of Military Ethics, 12(3), 2013, 233.

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