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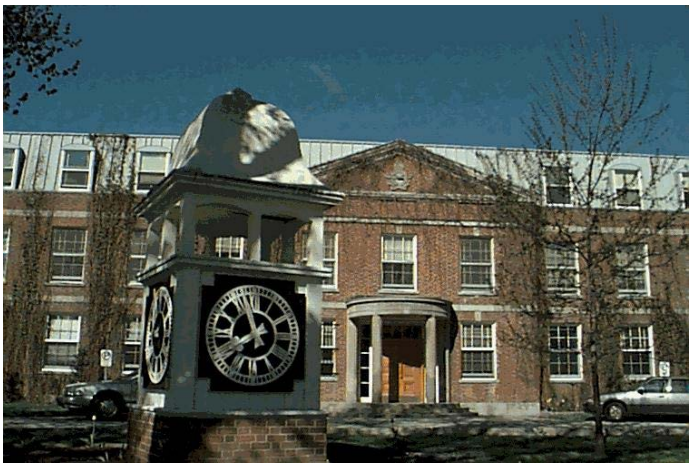

ADDITIVE MANUFACTURING: A CANADIAN IMPERATIVE

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ADDITIVE MANUFACTURING: A CANADIAN ARMY IMPERATIVE

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AIM

1. As far back as 2007, the Canadian Army (CA) recognized, "sustainment of forces in the future security environment will place extreme demands upon combat service support (CSS) units and elements."[1] Within the Adaptive Dispersed Operations (ADO) construct, tactical self-sufficiency while engaged in simultaneous operations across the spectrum of conflict in a non-contiguous battle space begs the question, "what is the limit of dispersed sustainment?"[2] In response to this critical question, this paper explores the employment of Additive Manufacturing (AM), commonly known as 3D printing, and its potential benefits to the CA within the Future Operating Environment (FOE). To that end, the paper examines current AM initiatives within the United States Marine Corps (USMC) as an illustration of the multi-faceted applications of 3D printing and to inform CA leadership of potential areas for future resource investment.

INTRODUCTION

2. Over the past decade, multiple guidance documents were published by the Canadian Army Land Warfare Center regarding the CA of the future. In all cases, a common thread of sustainment challenges were outlined, citing the imperative for adaptive, integrated, flexible, and robust CSS.[3] Drilling down even further into the function of sustainment, the prevailing guidance recognizes capability gaps perpetuated by aging legacy equipment fleets which must be mitigated by careful prioritization of diminishing resources and the adoption of an "equipment culture" across the CA.[4] This cultural shift is one which favors the adoption of emerging and

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[1] Department of National Defence, B-GL-310-001/AG-001, *Land Operations 2021, Adaptive Dispersed Operations: The Force Employment Concept for Canada's Army of Tomorrow* (Kingston, Ontario: Canadian Army Land Warfare Centre, 2007), 33.
[2] *Ibid*., 33, 41.
[3] Department of National Defence, B-GL-300-000/AG-003, *Waypoint 2018: The Canadian Army Advancing Toward Land Operations 2021 (*Kingston, Ontario: Canadian Army Land Warfare Centre, 2015), 54-55.
[4] *Ibid*., 51.

disruptive technologies and will also very likely require the ability to manufacture locally in austere environments, as well as, "conduct in-field prototyping for immediate operational requirements."[5] In short, the CA must find innovative, cost-effective options to extend the life-cycle of its platforms, increase operational availability of mission essential combat equipment, and facilitate rapid material solutions to emergent threats. One extremely compelling solution to this problem set is 3D printing (i.e. AM).

3. Notwithstanding the CA's diligence in identifying the aforementioned sustainment requirements for the FOE, for which AM is well-tailored, the Department of National Defence (DND) has been much less explicit in its commitment to specific sustainment initiatives. For example, in *Strong, Secure, Engaged: Canada's Defence Policy* (SSE), the word "sustainment" appears 15 times, yet in most instances the word refers to costs associated with new equipment procurement. Moreover, in no case does the word incite clear direction on how or where the DND will invest in sustainment of current capabilities or rapid response to emergent operational requirements – both of which could be facilitated by the adoption of AM technologies. In a recent *Canadian Military Journal* article, Defence Research & Development Canada (DRDC) Senior Defence Scientist, Christopher Bayley and Engineering Technologist Michael Kopac assert that although AM implications for the CAF are mentioned on the "Future Security Environment 2013-2040" technologies watch list[6], CAF leadership is lacking in defining potential applications of AM. They further proclaim, "by identifying the breadth of potential applications that AM is capable of disrupting, a tipping-point is reached and the requirement to

[5] Department of National Defence, B-GL-007-000/JP-009, *Canada's Future Army, Volume 2: Force Employment Implications* (Kingston, Ontario: Canadian Army Land Warfare Centre, 2017), 58.
[6] Department of National Defence, A-FD-005-001/AF-003, *The Future Security Environment 2013-2040*. (Winnipeg: Chief of Force Development, 2014), 68-69.

invest in AM innovations will be realized."[7] Given the disparity between the CA's recognition of the potential benefits of AM within the sustainment function and the DND's current level of investment in 3D printing technologies across the force, it is prudent to study the USMC's AM initiatives to better understand the utility of AM in an expeditionary environment and help inform future investment decisions of the Canadian Government.

DISCUSSION

Force Shaping and Intelligence Preparation of the AM Adoption Battlefield

4. In 2014, the Marine Corps commissioned RWAppleton & Company, Inc. to provide a comprehensive overview of 3D printing technologies, describe the growth rate of the industry, and outline the potential benefits for implementation within the USMC.[8] The report detailed several potential advantages of AM for the Marine Corps, notably; reduced inventory footprint realized by a repository of Computer Aided Drafting (CAD) files and storage of raw materials vice parts on the shelf, reduced transportation costs via sending CAD files electronically instead of shipping physical assets, and service life extension of legacy equipment via rapid prototyping of obsolete components no longer available from the Original Equipment Manufacturer (OEM).[9] Perhaps most importantly, the report was the catalyst for the USMC's aggressive pursuit of a force-wide paradigm shift towards AM implementation – and it all started at the top.

5. On 24 September 2015, General Robert B. Neller assumed the Office of the Commandant of the Marine Corps (CMC) and shortly thereafter on 19 January 2016, he released Fragmentary Order (FRAGO) 01/2016: "Advance to Contact". In this order, the CMC outlined five focus

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[7] Christopher Bayley and Michael Kopac. "The Implications of Additive Manufacturing on Canadian Armed Forces Operational Functions." *Canadian Military Journal* 18, no. 3 (Summer 2018): 48, http://www.journal.forces.gc.ca/vol18/no3/PDF/CMJ183Ep47.pdf.
[8] Robert W. Appleton. *Additive Manufacturing Overview for the United States Marine Corps* (Sterling Heights, MI: RW Appleton and Company, 2014), 2.
[9] *Ibid*., 24.

areas he deemed vital to achieving future success. Among them were training/simulation/experimentation, integration with the naval and joint force, and modernization and technology.[10] In his conclusion, the CMC set the stage for a paradigm shift in favor of exploring concepts like AM when he said:

> … Innovation necessitates making hypotheses about the future operating environment that are then tested for validity, just as Marines did in the 1920s and 1930s. We may not find initial successes in all of our experimentation efforts, but our continued focus and persistence will lead to solutions that will enable our future force. This "disruptive" mindset must be pursued and fostered when found, or it will not sustain itself within our bureaucracy. We need creative leaders who think![11]

With the intent of the Corps' senior leader clearly outlined, Marines at all levels of the chain of command were compelled to move out aggressively towards AM experimentation wherever they perceived an opportunity.

6. Within six months of FRAGO 01/2016's release, Lieutenant General (LGen) Michael Dana, Deputy Commandant for Installations and Logistics (DC I&L) published Marine Administrative Message (MARADMIN) 304/16, which announced the first ever USMC Logistics Innovation Challenge. The purpose of the challenge was to solicit ideas from across the force within a short, 30-day period to address a specific logistics challenge outlined as follows:

> … Make Your Corps. Building off the international maker movement, imagine you have four weeks and unlimited resources to build a product to make your unit better using 3D printing or a similar technology. What would you make? Solutions can range from new rifle scopes to new radios to new vehicles. The purpose of this challenge is to expose Marines, Sailors and civilians to the tools, methods, and benefits of rapid prototyping, also known as "making." The making movement has been enabled by several recent technologies such as 3D printers, laser cutters, minicomputer numerical control (CNC) mills, easy-to-use computer aided design (CAD) software, simple sensors,

[10] United States Marine Corps. "Fragmentary Order 01/2016: Advance to Contact." (Washington, DC: Headquarters Marine Corps, Office of the Commandant, January 2016), 3.
[11] *Ibid*., 12.

> and inexpensive micro-computers. With the right tools and instruction, what might a Marine make? Would these solutions improve warfighting capability, either while in garrison or forward deployed?[12]

The message incentivized creative and thoughtful submissions with challenge winners rewarded with the opportunity to work directly with a sponsoring research & development lab to shape their ideas into working prototypes and ideally into a Marine Corps-wide fielding of their design.[13] The day after the MARADMIN was released, LGen Dana released a YouTube video announcing the innovation challenge. The video was less than 90 seconds long, featured himself engaged in common USMC training scenarios, and amplified the CMC's priority for innovation with total force participation as the critical element.[14]

7. By the end of the 30-day challenge period, the USMC received over 300 submissions and selected 17 winning proposals which included; ordnance and IED tool fabrication, aircraft rigid tube sampling kit[15], fractal antenna fabrication, modification of M777A2 (Howitzer) cables, adaptable and affordable 3D printed drones, and 3D models in support of tactical plans.[16] Winners ranged in rank from field grade officers all the way down to junior enlisted members and represented units from across the spectrum of the Marine Air Ground Task Force (MAGTF). The proposals addressed real world issues the Marines were facing every day and the suggested solutions carried the potential for tangible and significant impact to the lethality and combat readiness of the force. Perhaps most importantly, the sheer number of quality submissions received in an extremely short time span, and at minimal financial cost, indicated that the CMC's

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[12] MGen V.A. Coglianese. *Logistics Innovation Challenges* (Headquarters Marine Corps: MARADMIN 304/16, 141455Z JUN 16).
[13] *Ibid.*
[14] "Marine Corps Innovation Challenge." YouTube video, 1:22, posted by "Marines," 15 June 2016, https://www.youtube.com/watch?v=vECZ1lUsny4.
[15] "Marine Corps Partners with Army for 3-D Printed Technology Solutions," YouTube video, 4:03, posted by "U.S. Army Research Laboratory," 26 January 2017, https://www.youtube.com/watch?v=P9MP5P7HrvI.
[16] LGen Michael G. Dana. *Logistics Innovation Challenges Results Announcement, August 2016, Washington DC* (Headquarters Marine Corps: MARADMIN 492/16, 191828Z SEP 16).

intent for innovation in AM resonated with the force and the "disruptive mindset" he mentioned in his FRAGO was gaining traction.

8. Over the past two years, the USMC and the Department of the Navy (DON) published multiple guidance documents with specific direction regarding innovation initiatives and the testing, evaluation, and implementation of AM concepts.[17] The first iteration of these was MARADMIN 489/16 which announced the establishment of a Headquarters Marine Corps (HQMC) AM team and authorized immediate use of 3D printing technologies to produce consumable items and non-procurable (i.e. obsolete) repair parts.[18] Another was MARADMIN 594/17 which empowered commanders at the O-5 (LtCol) level to allocate unit funds to procure, manage, and utilize commercially available AM equipment and materials to design, manufacture, and employ approved items.[19] In May 2017, the DON released its AM Implementation Plan V2.0 which provided five objectives as follows:

> …1. Develop the capability to rapidly qualify and certify AM components 2. Enable end to end process integration of secure on-demand manufacturing with integrated digital AM data, infrastructure and tools
> 3. Formalize access to AM education, training and certifications for the DON workforce
> 4. Develop responsive AM related business practices, contracting, intellectual property, legal and liability guidance
> 5. Enable manufacturing agility through low volume production in maintenance and operational environments.[20]

The document also outlined a detailed plan of action and associated milestones for the DON's roll-out of AM adoption and iterative implementation. Of particular interest to the USMC, the plan described the concept of "weaponizing" the supply chain by leveraging

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[17] These guidance documents are too extensive to mention individually in this service paper, but are provided in the bibliography for future reference.
[18] LGen Michael G. Dana. *Interim Policy on the Use of Additive Manufacturing (3D Printing) in the Marine Corps* (Headquarters Marine Corps: MARADMIN 489/16, 161443Z SEP 16), 2-3.
[19] LGen Michael G. Dana. *Headquarters Marine Corps Procedural Guidance Update on the Management and Employment of Additive Manufacturing* (Headquarters Marine Corps: MARADMIN 594/17, 251833Z OCT 17), 3.
[20] Department of the Navy. *DON Additive Manufacturing (AM) Implementation Plan V2.0* (Washington, DC, 04 May 2017), 4. http://www.dtic.mil/dtic/tr/fulltext/u2/1041527.pdf.

AM's capacity to, "allow the warfighter access to specifically tailored components, systems, and munitions at the point and time of need."[21] With clear guidance and burgeoning advocacy from the senior leaders of the DON, by way of endorsement and fiscal investment, the Marine Corps embarked on an AM revolution which is rapidly evolving.

USMC Additive Manufacturing Initiatives and Successes

9. The Expeditionary Manufacturing mobile testing facility, known as "EXMAN" is a rapidly deployable trailer containing equipment and materials needed to execute AM applications in an austere environment. The debut version of the EXMAN for the USMC was introduced in March 2016 at Camp Pendleton, CA when it was delivered to the Marines of 1st Maintenance Battalion in partnership with Space and Naval Warfare Systems Command (SPAWAR).[22] To maximize utility of the trailer and the technologies within, the Marines received CAD software and 3D design training from SPAWAR engineers to a level of proficiency which enabled the trailer to be managed and maintained solely by the Marines of 1st Maintenance Battalion with only oversight and advisory support from SPAWAR.[23] Since delivery, EXMAN has been in a perpetual state of testing and evaluation including employment during Steel Knight 2017, a 1st Marine Division led exercise at Marine Corps Air Ground Combat Center Twentynine Palms, CA. During the exercise the EXMAN's AM technologies were used to rapidly prototype a Logistics Vehicle System Replacement (LVSR) mounting bracket which became

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[21] *Ibid,* 5.
[22] Lieutenant Colonel Foster Ferguson, Commanding Officer, 1st Maintenance Battalion, 1st Marine Logistics Group, telephone conversation, 6 September 2018. Maria Kelly Murphy. "Expeditionary Manufacturing Mobile Test Bed (EXMAN)," last modified 03 May 2016. http://www.secnav.navy.mil/innovation/Pages/2016/05/EXMAN.aspx.
[23] *Ibid.*

unserviceable. The bracket was designed and printed in plastic, tested for form, fit, and function, and then printed with metal to achieve a suitable replacement and return the vehicle to its full operational capability.[24] The aforementioned scenario is just one example of how AM capabilities delivered to an austere environment (i.e. via EXMAN) can minimize the constraints of the traditional supply chain and enhance our forces' ability to maintain operational tempo while forward deployed.

10. Although more testing is needed regarding the EXMAN's deployability, to include its capacity to operate from sea-based platforms, the AM technologies within EXMAN, even when used in a garrison environment, are undeniable and have been adopted in multiple locations across the Marine Corps. Furthermore, many capability requirements have gone from proof of concept designs to production and implementation using the AM technologies resident in EXMAN. These include; the engine connecting rod for the Amphibious Assault Vehicle (AAV), impeller fan for the M1A1 Abrams tank, power knob for night vision optic (AN/PVS-17c), camera mount for the MK-2 Explosive Ordnance Disposal (EOD) robot, fixed and rotary wing Unmanned Aerial Systems (UAS) components, and 3D terrain models.[25] As an illustration of the impact just one of these can have on the force, the AAV engine connecting rod, when ordered through the supply system, has a lead time of 152 days at an OEM cost of $561.38 (not including shipping costs). Using AM technologies, the Marines of 1st Maintenance Battalion produced a

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[24] "Steel Knight: The Ex-Man Returns." DVIDS video, 1:41, posted by "First Marine Logistics Group," 12 December 2016, https://www.dvidshub.net/video/499628/steel-knight-ex-man-returns.

[25] Compilation of references from: Zach Daugherty and Andrew Heiple, "Additive Manufacturing Solutions in the United States Marine Corps," (Naval Postgraduate School, 2017), 25-26, "3D Printing: The Future Of Warfare?" YouTube video, 5:01, posted by "Forces TV," 07 September 2017. https://www.youtube.com/watch?v=LKiESPbU6cQ, "SoCal Ship-to-Shore Exercise: The Amazing Ex-Man." Defense Visual Information Distribution Service (DVIDS) video, 1:30, posted by "First Marine Logistics Group," 04 May 2017. https://www.dvidshub.net/video/522465/socal-ship-shore-exercise-amazing-ex-man, and Lieutenant Colonel Foster Ferguson, Commanding Officer, 1st Maintenance Battalion, 1st Marine Logistics Group, telephone conversation, 6 September 2018.

suitable replacement rod in 35 hours at a cost of $98.00.[26] Certainly, the production of a suitable replacement rod at less than one-fifth of the OEM cost is desirable. Perhaps even more important however, is the reduction in Customer Wait Time (CWT) by 149 days and the rapid return of a combat critical asset to the fight.

11. Among the Marine Corps' pursuit of multiple AM initiatives, there is one unique line of effort which is paying huge dividends. Innovation Boot Camp, aptly nicknamed, "MacGyver Camp" by the Marines who have attended, is a week long course provided by Building Momentum LLC, an Alexandria, Virginia based company who trains students to leverage technology, including AM, to solve problems.[27] Since January 2017, over 200 Marines across the Corps from trades including mechanics, infantry, communications, and signals intelligence have completed the course.[28] The curriculum is fast-paced by design and teaches Marines critical AM prototyping skills such as welding, plasma cutting, circuitry, and CAD software utilization, all of which are necessary to complete the capstone event of the course – a simulated, real-world combat scenario.[29] While certainly the Marines leave Innovation Boot Camp with tangible AM skills to implement in their day-to-day operations, perhaps the larger benefit is their shift in mindset and new found bias towards leveraging the innovative nature of AM to solve almost any problem.

CONCLUSION

12. On 7 March 2018, the CMC testified before the Congressional Defense Committees and provided the posture of the USMC. In his testimony, he indicated

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[26] Lieutenant Colonel Foster Ferguson, Commanding Officer, 1st Maintenance Battalion, 1st Marine Logistics Group, telephone conversation, 6 September 2018.
[27] Josh Dean. "Making Marines Into MacGyvers," (*Bloomberg Businessweek*, 20 September 2018), https://www.bloomberg.com/news/features/2018-09-20/making-marines-into-macgyvers?srnd=premium-canada.
[28] *Ibid*.
[29] *Ibid*.

Marines are at the forefront of optimizing the potential of AM in garrison and in austere environments.[30] He pointed out the USMC has over 70 3D printers in use across the force and described the ways in which the Corps is fostering creativity via the "challenge competitions" and "innovation boot camp" previously described in this paper. He ended this section of his testimony by emphatically declaring, "This [AM] is the future and your Marines are working to change the way we conduct logistics in combat."[31]

13. As illustrated in this paper, the USMC's iterative approach to introducing AM into the fleet has garnered significant results. The clear intent, firm advocacy, and creative delivery of guidance from the top leaders of the organization fostered an environment where a shift in mindset was encouraged and rewarded. Moreover, the Corps did not simply throw money at the problem and depend on commercial industry or academia to develop solutions; rather, it engaged Marines at all levels to take stock in the issues and be critical contributors in the design processes which will ultimately change the way we fight and win.

14. The CA's aging combat equipment fleets, coupled with the high likelihood of conducting dispersed operations in a non-contiguous battle space against an enemy who is rapidly closing the technology gap, provide ample reason to seriously consider AM as a vital contributor to success in the FOE. Even amidst the challenges of a constrained fiscal environment, the CA cannot afford to neglect investment in this area.

RECOMMENDATIONS

15. The Canadian Army would do well to study the AM efforts of the USMC and pursue a similar adoption and implementation strategy. Furthermore, the CA should

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[30] House of Representatives, House Appropriations Committee - Defense, *Statement of General Robert B. Neller, Commandant of the Marine Corps, on the Posture of the United States Marine Corps* (7 March 2018), 7.
[31] *Ibid*.

leverage its longstanding partnership with the USMC to engage in collaborative AM efforts during joint, bi-national, and multi-national exercises and operations. In the near future, the CA should seek opportunities to send its most technologically savvy soldiers to the “Innovation Boot Camp” described earlier in this paper. Finally, as soon as possible, the CA should invest in at least one expeditionary AM capability similar to the USMC’s EXMAN. This significant, yet worthwhile investment will provide a platform from which to train personnel in AM technologies, foster creativity and ownership in the development of logistics solutions, and explore how the CA, and by extension the Canadian Armed Forces, may best employ AM in support of their core mission sets.

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