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EMERGING SPACE TECHNOLOGY: HOW THE CAF CAN INCREASE ITS SPACE POWER

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AIM

1. This service paper aims to explore the emerging trends and advancement of technologies that the Canadian Armed Forces (CAF) can look to leverage as it builds its space capabilities. This paper will define the possibility and investigate the pros and cons of several technologies such as small and other relative satellite classifications, artificial intelligence and machine learning, nanotechnologies, and space robotics as potential investment areas.

INTRODUCTION

2. The space domain is critical for civil and military sectors with a wide range of applications from telecommunications technology, weather forecasting, disaster monitoring and management, and financial transactions. Space has become intertwined and enables everyday life for all Canadian citizens. The growing dependence on the space domain from the civil and military aspects makes it a critical domain for the Canadian Armed Forces (CAF) to continue to grow a creditable space capability that is able to defend and protect its interests in the space domain. The Strong, Secure, Engaged: Defense Policy from 2017 identifies that the Royal Canadian Air Force (RCAF) will lead the Department of National Defense (DND) space program and mandates it to acquire capabilities to improve situational awareness, targeting, and communications. In recent years the space domain has become increasingly competitive, from the growth of state-sponsored programs to the exponential growth of the commercial industry, which provides opportunities for the CAF to leverage collaboration from both commercial companies and its allies to advance its space capability. There are many technologies that the CAF can look to invest in or keep close watch as they mature. The technologies include small satellites, artificial intelligence and machine learning, nanotechnologies, and space robotics.

DISCUSSION

3. One of the most noticeable trends in the commercial space industry is shifting focus from large satellites to small satellites in the Low Earth Orbit (LEO). Elizbeth Howell explains the shift in focus because "the significant advancements in camera technology and computer miniaturization is allowing companies to do optical imaging or radar observations using smaller and smaller satellites."[1] In addition, the shifting focus and technical advances are highlighted by the commercial market growth, which was estimated at $12.6 Billion (USD) in 2018 and predicted to be $42.8 billion (USD) by 2028.[2] The rapid proliferation of commercial use has all nations thinking about how the smallsat concept can be applied for military applications. While the United States (US) Military leads the world in space capability by the sheer numbers of satellites, they are assessing the application of using smallsats for multiple mission sets like

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[1] Elizabeth Howell, "US Military May Start Moving towards Launching Fleets of Tiny Satellites," Space.com (Future US Inc, April 1, 2020), https://www.space.com/us-military-small-satellite-cubesat-constellations.html.
[2] EUROCONSULT, " Euroconsut Research Projects Smallsat Market to Nearly Quadruple over next Decade," Euroconsult-ec.com (Euroconsut, June 23, 2021), https://www.euroconsult-ec.com/press-release/euroconsult-research-projects-smallsat-market-to-nearly-quadruple-over-next-decade/.

communication, missile defense, alternative navigation system, and intelligence, surveillance, and reconnaissance (ISR).[3] In addition, countries such as China[4], Russia, India, and other NATO allies are using smallsat to level the battlefield in terms of capability due to the pros outweighing the cons.

4. The classification of spacecraft is based on its mass. NASA defines a smallsat as "anything under 180 kilograms, and the Smallsat family further broke down and differentiated by size and mass."[5] As technology across many different areas continues to mature, the trend of satellites becoming smaller and smaller will continue. The legacy approach of creating large, highly robust, and reliable satellites is expensive and involves slow design cycles, long life spans, and low production rates.[6] The benefit of generating military capability through smallsats far outweigh the legacy methods. Some pros include reduced manufacturing costs, quicker production timeline, reduced launch cost, and inherent protection benefits. An example of how significant the reduction in manufacturing cost can be is the US Missile Defense Agency, CubeSat Networked Communications Experiment Block 1 satellite. They state, "the cost per satellite is about $1.3 million versus hundreds of millions required for traditional satellite construction."[7] This drastic decrease in price per unit is due to off-the-shelve technology. In addition, off-the-shelve technology leads to a quicker production timeline because you don't have to build unique components, and it doesn't require testing, potentially reducing production from years to months.[8] Furthermore, there is a cost-benefit in launch cost because the mass and the orbital destination usually determine the price. In addition, the introduction of the commercial launch industry and reusable rockets further decreased the cost to LEO by a factor of 20.[9] Compared to the legacy model, a smallsat constellation comprised of many satellites versus just one making it harder to target and more challenging to degrade as a whole. This inherent defense mechanism is known as resiliency and redundancy; a smallsat constellation provides this by the orbital plane it resides in and the number of smallsats required for global coverage. While there are advantages, some disadvantages include a short life span, orbital decay due to decreased hardening, and reduced signal transmitters. All these disadvantages are being attacked by the

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[3] Howell, US Military May Start.

[4] One example China's smallsat commercial expansion is the DFH-3E satellite designed by the China Academy of Space Technology, a subsidiary of the State-owned space conglomerate. China will be offering this as an affordable internet netowrk solution for other nations. See Zhao Lei, “New Small Satellite Platform Debuts,” Chinadaily.com (China Daily , October 4, 21AD), https://www.chinadaily.com.cn/a/202110/04/WS615a3adea310cdd39bc6d014.html.

[5] Elizabeth Mabrouk, “What Are SmallSats and CubeSats?,” NASA.gov (NASA, March 13, 2015), https://www.nasa.gov/content/what-are-smallsats-and-cubesats.

[6] SAIC, “Smaller Satellites Present New Ways to Leverage Space Resources,” SAIC.com (SAIC, March 17, 2021), https://www.saic.com/features/space/smallsats-present-new-ways-to-leverage-space-resources.

[7] David Vergun, “Nanosatellites Could Play Pivotal Role in Defense against Enemy Missiles,” U.S. Department of Defense (DoD News , July 12, 2021), https://www.defense.gov/News/News-Stories/Article/Article/2685840/nanosatellites-could-play-pivotal-role-in-defense-against-enemy-missiles/.

[8] John J. Klein, “Understanding Space Strategy: The Art of War in Space ,” in Understanding Space Strategy: The Art of War in Space (Milton Park, Abingdon, Oxon: Routledge, 2020), p. 48-124, 191.

[9] Harry Jones, “The Recent Large Reduction in Space Launch Cost ,” Texas Tech University (NASA, July 8, 2018), https://ttu-ir.tdl.org/bitstream/handle/2346/74082/ICES_2018_81.pdf?sequence=1&isAllowed=y, 1.

plethora of space start-up companies looking to make their mark in the civil or military smallsat sectors.

5. The evolution of artificial intelligence and machine learning has been incorporated into our daily lives, and most of us haven't even noticed. The ordinary person uses these two technical terms interchangeably, but by the industry standard, they have different meanings. Artificial intelligence is a technology that enables a machine to simulate human behavior, while machine learning is a subset of artificial intelligence, which allows a device to learn from past data without programming explicitly automatically.[10] An example of machine learning is the targeted marketing ads on your social media platforms.[11] At the same time, artificial intelligence is being used in iPhone's Siri and Googles's Alexa applications.[12] Lastly, companies like Tesla are looking to combine these two to create the first autonomous driving car.[13] These are elementary examples of how these technologies are being integrated into our daily lives, but also, the exponential growth in their market size shows just how important they are to our future. The Grand View Research market size report shows that "artificial intelligence has grown from $2.57 billion in 2017 to $62.35 billion in 2020."[14] While machine learning, a subset of artificial intelligence, has grown from $1.03 billion in 2017 to 8.81 billion in 2022.[15] These straightforward examples of how these two technologies are incorporated into our lives and the rapid expansion in their global market size prove that as society accepts and integrates these technologies, nations are looking to apply them as a critical part of modern warfare in the future. For example, John Keller's military plus aerospace article states that "the US Department of Defense plans to invest $874 million (USD) on artificial intelligence and machine learning technologies in the fiscal year 2022. Which is a 50 percent increase from the previous year."

6. There are two ways that the US military is researching these technologies to employ them through the space domain that the CAF could take advantage of, the first being autonomous command and control (C2) of space satellites and the second being an advanced battlefield network for targeting. The emergence of autonomous satellite C2 is a technology that the US Air Force has been researching its utility since 2011 to scale its ground station from a Space Operation Center onto a single laptop, which will remotely direct the ground system from the

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[10] Java Point , "Difference between Artificial Intelligence and Machine Learning - Javatpoint," www.javatpoint.com (Java point), accessed January 20, 2022, https://www.javatpoint.com/difference-between-artificial-intelligence-and-machine-learning.

[11] "How Does Facebook Use Machine Learning to Deliver Ads?," Facebook for Business (Meta , June 11, 2020), https://www.facebook.com/business/news/good-questions-real-answers-how-does-facebook-use-machine-learning-to-deliver-ads.

[12] "10 Examples of Artificial Intelligence in Our Everyday Lives," LucidPix (LucidPix, December 21, 2021), https://www.lucidpix.com/10-examples-of-artificial-intelligence-in-our-everyday-lives/.

[13] Ben Dickson, "Tesla AI Chief Explains Why Self-Driving Cars Don't Need Lidar," VentureBeat (VentureBeat, July 3, 2021), https://venturebeat.com/2021/07/03/tesla-ai-chief-explains-why-self-driving-cars-dont-need-lidar/.

[14] Grandview Research, "Artificial Intelligence Market Size Analysis Report, 2021-2028," Artificial Intelligence Market Size Analysis Report, 2021-2028 (Grandview Research, June 2021), https://www.grandviewresearch.com/industry-analysis/artificial-intelligence-ai-market.

[15] Markets and Markets , "Machine Learning Market," Market Research Firm (Markets and Markets , September 2017), https://www.marketsandmarkets.com/Market-Reports/machine-learning-market-263397704.html.

host hardware micro-cloud computing architecture.[16] An example of this application is, Italian start-up company AIKO and their Mission Replanning Through Autonomous Goal gEneration (MiRAGE), "which allows the spacecraft to perform autonomous replanning, to detect events (internal and external), and to react accordingly, ensuring fulfillment of mission objectives without delays introduced by the decision-making loops on the ground."[17] These systems aim to exploit these technologies to perform routine operations and any maintenance activities required. The result is removing the human from the loop or minimizing the personnel necessary to maintain a constellation of satellites. The CAF could easily leverage technology similar to the MiRAGE concept to expand its space capability without additional personnel requirements.

7. The RCAF has been mandated to acquire space capability to improve targeting.[18] The advancement in artificial intelligence and machine learning is allowing a new-age system, throughout all domains, to efficiently compute and handle large amounts of data to lead the combat system to the correct answer. The Advanced Battlefield Network prototype that the US Army recently tested seeks to answer the explicit mandate laid out by the Strong, Secure, Engage policy. The Advanced Battlefield Network is a new system that will enable overhead satellite imagery for beyond-line-of-sight targets; using artificial intelligence; it fuses data from commercial imagery satellites then transports the images to the battlefield via communications satellites where soldiers can determine the threat.[19] This new space layer aims to decrease the kill chain at the tactical level from days to hours to minutes giving the US Army a massive advantage over its adversaries. As defined by the RCAF *Space Power Doctrine*, this capability is an example of Space Force Enhancement, "which is the ability to deliver strategic effect through space-based operations."[20] Employing a capability similar to this for the Canadian Army would transform how the Army fights future conflicts.

8. Since 1981, the first Canadarm was launched aboard Space Shuttle Columbia, Canada has been a leading nation in space robotics.[21] The CAF can leverage their country's expertise in the space robotics industry and the progression of miniaturization to tackle two waves of the future concepts: on-orbit satellite servicing and space debris removal. The on-orbit servicing concept is not a novel idea; NASA completed the SolarMax mission in 1984, a human-crewed space shuttle mission that successfully replaced two defective components.[22] The next iteration of this on-orbit

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[16] US Air Force , "USAF, Lockheed Agree on Satellite C2 R&D Project," Airforce Technology, December 15, 2011, https://www.airforce-technology.com/news/newsusaf-lockheed-agree-on-satellite-c2-rd-project/.

[17] The European Space Agency , "Aiko: Autonomous Satellite Operations Thanks to Artificial Intelligence," ESA (The European Space Agency , January 28, 2019), http://www.esa.int/Applications/Telecommunications_Integrated_Applications/Technology_Transfer/AIKO_Autonomous_satellite_operations_thanks_to_Artificial_Intelligence.

[18] Canada Department of National Defence, Strong, Secure, Engaged, p. 39.

[19] Nathan Strout, "Army Approves Rapid Development of Tactical Space Layer," Defense News (Defense News, May 3, 2021), https://www.defensenews.com/battlefield-tech/space/2021/05/01/army-approves-rapid-development-of-tactical-space-layer/.

[20] Canada. Department of National Defence. Royal Canadian Air Force. Royal Canadian Air Force Doctrine Note 17/01: Space Power. Department of National Defence, 2017, 1-43.

[21] Canadian Space Agency, "Flight History of Canadarm," Canadian Space Agency (/ Gouvernement du Canada, March 31, 2021), https://www.asc-csa.gc.ca/eng/canadarm/flight.asp.

[22] John Wilford, "Space Crew to Attempt Historic Repair Mission," The New York Times (The New York Times, August 28, 2018), https://www.nytimes.com/.

serving is creating a satellite that can upgrade, inspect, and refuel other satellites. This capability could fundamentally change space operations by significantly lowering costs through expanding the satellite's life span and reducing space debris. So why would the CAF or Canada be inclined to invest in this technology? The *Strong, Secure, Engaged: Defense Policy* states, "[23] Canada can demonstrate leadership by promoting the military and civilian norms of responsible behavior in space required to ensure the peaceful use of outer space." Investing in space robotics for on-orbit serving and debris removal would endorse responsible behaviors and norms to the global community. In addition, it would provide a capability that promotes the peaceful use of the space domain while delivering a capability that could reduce cost and increase the longevity of each satellite. The positive of employing this technology is hoping countries use it peacefully, but the reality is that anything put in space can become a weapon. A robotic arm on a satellite makes it a multi-use kill vehicle compared to the collision of two satellites.

9. The removal of debris has been a critical focus as space has become commercialized, resulting in it becoming more and more congested every day. As stated by Ramin Skibba's article, *The US Space Force wants to Clean Up Junk in Orbit*, "The Pentagon currently tracks 27,000 pieces of debris in orbit, which include everything from dead spacecraft and used-up rocket boosters to the detritus left behind from satellite-destroying missile tests."[24] In addition, due to physics, each of those 27,000 pieces becomes a projectile just waiting to take out a nation's operational satellite. This debris is causing multiple satellites and even the International Space Station to move a considerable amount of times, and each move decreases the life span of that satellite. Similar to the impact of on-orbit serving, applying Canadian expertise in space robotics to debris removal would dramatically increase the CAF's Space Influence[25] throughout the global space community.

10. The last emerging technology that the CAF should track carefully is the application of nanotechnology in space; it has the potential to unlock a new realm of possibility when it comes to space capability and exploration. Nanotechnology in Space Exploration defines nanoscience,

> nanoscience is the study of the fundamental principles of matter at the scale of ~1-100 nanometers, while nanotechnology is the application of such knowledge to making materials and devices. Furthermore, at the nanometer scale, many properties of matter are different from the properties at the macroscale.[26]

Understanding these properties and finding ways to harness them is the key to unlocking its potential application. Nano Werk states, "One application currently being investigated is the nanotechnology electric propulsion concept which is the process of electrostatically charging and

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[23] Canada Department of National Defence, Strong, Secure, Engaged, p. 57.
[24] Ramin Skibba, "The US Space Force Wants to Clean up Junk in Orbit," Wired (Conde Nast, November 17, 2021), https://www.wired.com/story/the-us-space-force-wants-to-clean-up-junk-in-orbit/.
[25] The Space Power Doctrine defines Space Influence as the function of influencing an adversary's behavior in the space domain. See previously cited Canada, Department of National Defence, Space Power Doctrine, p. 20.
[26] National Science and Technology Council , "Nanotechnology in Space Exploration ," Nano.gov (National Science and Technology Council , April 2004), p. V, https://www.nano.gov/sites/default/files/pub_resource/space_exploration_rpt_0.pdf.

accelerated nanoparticles as a propellant."[27] The result would of this system drastically reduce the amount of fuel required for each satellite. Kerry Taylor Smith discloses that "95% of the weight of a spacecraft at launch is fuel, leaving only 5% for the craft itself."[28] In addition, the reduced weight of each payload will also reduce launch cost; as previously stated, launch cost is directly related to the mass and its orbit destination. There are many more potential applications, but unlocking the possible use of nanotechnology propellant would significantly reduce the cost barrier for implementing future space capabilities.

RECOMMENDATIONS

11. As space-based systems and services continue to become even more critical parts of how the CAF and Allies conduct modern warfare, the CAF must continue to enhance their space capability. Specifically, the CAF should leverage the proliferation of space by applying the emerging trend of smallsats capability. The investment in smallsats technology is a way for the CAF to create native space capability while decreasing the reliance on its strongest ally, the US Military, to provide space effects. As noted prior, the commercialization of space has reduced the cost of acquiring space capability, but it is vital to prioritize capability delivery with current budget constraints. The recommendation of this paper is to prioritize investment in the following mission sets ISR, communication, and space situational awareness capabilities through the use of smallsat constellations.

12. In conjunction with the investment in smallsats to advance the CAF space capability, the CAF should utilize the advancements in artificial intelligence and machine learning technologies. Specifically, autonomous C2 technology is recommended to lessen the personnel required for current and future space operations. The pandemic and other factors have driven the CAF manning to roughly 12,000 personnel short, which will have a lasting effect on all services.[29] Investing in autonomous technology relieves the space enterprise of competing with other defense priorities for critical human resources that the CAF will continue to have to balance into the future.

CONCLUSION

13. The space domain will continue to become increasingly competitive, from the growth of state-sponsored programs that take notice of the advantages that space can bring as a force enabler and from the exponential growth of the commercial industry. This paper only identified and recommended some of the many opportunities the CAF could invest in to enhance its space capabilities through partnerships with commercial entities or allies. The technologies identified included small satellites, artificial intelligence and machine learning, nanotechnologies, and space robotics. The combination of *Strong, Secure, Engaged: Defense Policy* and RCAF *Space*

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[27] Michael Berger, "Nanotechnology in Space," Nanotechnology, July 2, 2021, https://www.nanowerk.com/nanotechnology-in-space.php.
[28] Kerry Taylor-Smith, "What Nanomaterials Are Used in Space?," AZoNano.com, September 7, 2018, https://www.azonano.com/article.aspx?ArticleID=4983.
[29] The Canadian Press, "Military Dealing with More than 10,000 Unfilled Positions amid Growing Pressures," National Post (National Post, January 18, 2022), https://nationalpost.com/pmn/news-pmn/canada-news-pmn/military-dealing-with-more-than-10000-unfilled-positions-amid-growing-pressures.

Power Doctrine have laid out the vision for the Canadian space domain, and building on this foundation will be essential for the future success of the CAF.

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