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SPACE DEFENCE: STRATEGIES ON HOW TO PROTECT THE HIGHEST GROUND

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AIM

1. The peaceful exploration and use of space is a noble and lofty goal that Canada must continue to promote. There is no denying that in this era of global competition, space is a critical domain that is increasingly contested. Similar to other developed nations, Canada's reliance on space is too critical to its economic and military prosperity to leave unprotected. The purpose of this paper is to inform on the possible threats to the Royal Canadian Air Force’s (RCAF) space capabilities and investigate strategies of both active and passive defence that will increase its resilience against these threats. This paper will first examine resilience strategies against the threats of space debris, kinetic effects and non-kinetic effect. Finally, it will examine resilience through new disruptive technologies such as operating in Very Low Earth Orbit (VLEO), the miniaturization of space assets and air-breathing electric propulsion. Due to scope, this paper will refrain from engaging into civilian space asset mobilization, electronic/jamming and cyber, domains which need to be considered separately through more of a whole of government approach.

INTRODUCTION

2. The Canadian Armed Force (CAF) relies on space assets to provide positional navigational information, intelligence surveillance and reconnaissance (ISR), communications, geomatics and weather predictions. These technologies give the CAF and its allies an edge in global operations and as such will be seen as potential targets by enemies and competitors alike. Space assets are often complex unique systems that are

highly expensive and are extremely difficult to replace due to their per-unit manufacturing and launch cost. However, recent technologies and the advent of orbital launch by private enterprise have significantly brought down the cost of access to space. As such, Strong Secure Engage mandates the CAF to defend and protect its military space capabilities.[1]

DISCUSSION

3. For all the military and economic capabilities space has brought to the CAF, it has also created equivalent vulnerabilities. Nations that traditionally have had the means to put resources in orbit are signatories of the space treaties supporting international cooperation and the use of outer space for peaceful purposes. Article IV of the *Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies* bans only the use of nuclear and other weapons of mass destruction (WMD) in space with no mention of conventional weapons.[2] Further complications arise when immature nations in the space domain conduct highly controversial, live anti-satellite (ASAT) missile testing with detrimental effect to all space fairing nations due to the resulting debris. DND tasked with the defence of our space capabilities, is actively trying to foster and subsidize innovative ways to provide defensive capabilities as seen by the "Shields Up" project[3] in order to mitigate against the threats of the weaponization of space. As shown in the following

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[1] *Canada Defence Policy Report*, a)15.
[2] *United Nations Treaties and Principles on Outer Space, (2002)*: 4.
[3] David Pugliese, "'Shields Up': Defence Department Looks for New Ways to Protect Canada's Satellites, with a Nod to Star Trek | National Post," *National Post*-09-23T20:11:19+00:00, 2019a. https://nationalpost.com/news/canada/shields-up-defence-department-looks-for-new-ways-to-protect-canadas-satellites-with-a-nod-to-star-trek.

quote from the Center for Strategic and International Studies, our closest space allies share this concern:

> … recently, our adversaries have been working to bring new weapons of war into space itself ... China and Russia are also aggressively working to incorporate anti-satellite attacks into their warfighting doctrines…As their actions make clear, our adversaries have transformed space into a warfighting domain already. Vice President Mike Pence[4]

Defence Against Space Debris

4. Regardless of any present or future threat assessment on the use of force by our adversaries, man-made space debris already litters our orbits and threatens Canadian assets. According to data provided to the national post by DND, total debris numbers around 129 million with estimates of 34,000 greater than 10 centimeters, 900,000 between one and 10 centimeters and up to 128 million between one millimetre and one centimeter.[5] To make matters worse, a nation conducting an ASAT test can add up to 300,000 pieces per event and threaten peaceful endeavors such as the International Space Station (ISS).[6] The RCAF is already a leader in the monitoring of space debris with its satellite SAPPHIRE that provides data to Canada and the US Space Surveillance Network (SSN). This invaluable commitment will be renewed by its follow-on capabilities Surveillance of Space 2 (SofS 2), which will also feed the SSN through the

[4] "Remarks by Vice President Pence on the Future of the U.S. Military in Space."https://www.whitehouse.gov/briefings-statements/remarks-vice-president-pence-future-u-s-military-space/ (accessed Oct 15, 2019).
[5] David Pugliese, "Defence Department Asks Canadian Scientists to Tackle Space Junk Problem | National Post," -08-01T21:24:05+00:00, 2019b. https://nationalpost.com/news/defence-department-asks-canadian-scientists-to-tackle-space-junk-problem. Even the smallest debris carries very destructive power against space assets due to its extremely high velocity. Kinetic energy equals half times mass times the squared of the velocity.
[6] Rick Noack, "'Terrible' Antisatellite Test by India Endangers International Space Station, NASA Says," *Washington Post*-04-02T06:33-500, 2019. https://www.washingtonpost.com/world/2019/04/02/terrible-antisatellite-test-by-india-endangers-international-space-station-nasa-says/.

U.S. Joint Space Operations Center (JSpOC).[7] Generally speaking, there are three types of defences against space debris; passive, active and operational.

a. Passive Defences. Even with the best debris monitoring systems impacts happen regularly especially in Low Earth Orbit (LEO), as witnessed by Canadian assets on the International Space Station (ISS) (Canada's Mobile Servicing System and Canadarm2)[8]. Currently passive defence relies on physical shields which can be improved with materiel research.[9] The RCAF can capitalise on research with other Canadian institutions. For example, a new high speed impact research facility at the University of New Brunswick is capable of creating projectiles of 20 g to speeds of up to 8 km/s. [10] Improvements in the effectiveness and weight of monolithic and spaced shielding (otherwise known as whipple shield) could offer the following advantages: increased protection for currently protected structures and weight savings allowing for a better distribution of available shielding.

b. Active Defences. The simplest active defence is to engage in debris collision avoidance maneuvers, as has been done previously to protect Canadian space assets such as RADARSAT-1, RADARSAT-2, SCISAT-1 and MOST.[11]

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[7] Government of Canada, National Defence, "Surveillance of Space 2 - Defence Capabilities Blueprint," http://dgpaapp.forces.gc.ca/en/defence-capabilities-blueprint/project-details.asp?id=1920 (accessed Oct 17, 2019).
[8] "Inter-Agency Space Debris Coordination Committee."https://www.iadc-home.org/agencies_csa (accessed 17 Oct, 2019).
[9] *Read "Orbital Debris: A Technical Assessment" at NAP.Edu*The National Academies Press, 1995)122. doi:10.17226/4765. https://www.nap.edu/read/4765/chapter/1.
[10] UNIVERSITY OF NEW BRUNSWICK, "High-Speed Impact Research and Technology Facility," https://navigator.innovation.ca/index.php/en/facility/university-new-brunswick/high-speed-impact-research-and-technology-facility
[11] "Inter-Agency Space Debris Coordination Committee…

Although effective, this approach is inefficient due to fuel usage. Modern approaches aim at using direct energy weapons to deflect or destroy smaller debris, however the current limitation is in detection capabilities (hypervelocity debris 100 kilometers away only take about 5 seconds to travel to target). Canada is already a leader in space-based debris detection, close in detections for the use of active space debris defence is a niche capability that could be explored to further the development of space-based energy weapon protection.

c. Operational Defences. This type is achieved through physical design (oversizing/duplicating critical component) and operational behavior (orbit selection, optimal orientation of space craft to protect critical component).[12] This defence can also be achieved by redundancy in having more satellites in orbit than required which will be discussed in para 8.

5. A key action to reducing space debris lie in removing larger derelict objects that have the potential to create seas of debris in the event of a collision.[13] This is an area that is led by the Europeans where the RemoveDEBRIS satellite has already conducted space demonstrations of net and harpoon capture of space objects.[14] Canada is a world leader in space robotics and could provide invaluable expertise in this field. A native capability such as this would be invaluable to our allies and would act as a deterrence to other nations trying to use space-based robotics as a weapon against RCAF space assets.

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[12] *Read "Orbital Debris: A Technical Assessment"* …, 129.
[13] J. C. Liou and N. L. Johnson, "PLANETARY SCIENCE: Risks in Space from Orbiting Debris," *Science (New York, N.Y.)* 311, no. 5759 (Jan 20, 2006), 340. doi:10.1126/science.1121337. https://www.ncbi.nlm.nih.gov/pubmed/16424326.
[14] Airbus, "Testing Technology to Clear Out Space Junk," https://www.airbus.com/space/space-infrastructures/removedebris.html

Defence Against Kinetic Weapons

6. For humanity, launching and striking down satellites have gone hand-in-hand; the first ASAT weapon was tested by the United States in 1959, just two years after the launch of Sputnik. Kinetic effects on space capabilities can be delivered in a direct-assent or co-orbital manners. An enemy could conduct a kinetic strike on any ground nodes of a space system with the same short-term effect but would incur the disadvantage of having to openly strike a nations sovereign territory. Conversely, the same nation could launch an ASAT missile from its own territory or satellite. As per most ASAT solutions, an advanced source of guidance is required to acquire and track satellites from either earth or space. The use of these missiles would be visible due to their destructive effects and are likely very attributable.[15] The lack of available data in open source literature on the direct defence or counter measures against ASAT missiles, suggests that current solutions are either technologically not viable or highly experimental and secretive. The only avenues to counteract these ASAT according to literature is to either conduct a pre-emptive strike on enemy satellites, thereby preventing their ability to retaliate, or create a sufficient ASAT capability that the weapons themselves act as deterrence against their use by the enemy.[16]

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[15] Todd Harrison, Kaitlyn Johnson and Thomas G. Roberts, *Space Threat Assessment 2019* Center for Strategic and International Studies,[2019]). https://search.proquest.com/docview/2218043109.

[16] Mark A. Gubrud, "Chinese and US Kinetic Energy Space Weapons and Arms Control," *Asian Perspective* 35, no. 4 (Oct 1, 2011), 617-641. doi:10.1353/apr.2011.0026. https://www.jstor.org/stable/42704774.;Alexander Chanock, "The Problems and Potential Solutions Related to the Emergence of Space Weapons in The21st Century," *Journal of Air Law and Commerce* 78, 707.

Defence Against Non-Kinetic Effects

7. Non-kinetic attacks can take place in the physical, electronic or cyber domain. Direct physical attacks include the use of lasers, high-powered microwaves (HPM), and electromagnetic pulse (EMP) weapons. Depending on the intensity of the incoming energy, these types of attacks can blind, degrade or damage critical satellite systems such as solar panels and mission systems such as sensors.[17] Space-based high power lasers remain unlikely for the foreseeable future first due to the massive energy requirements that cannot be realistically collected by solar panels, and second due to the exhaust of hot gasses by chemical lasers that would hinder accurate targeting (compounded by the weight fuel issue).[18] Therefore, the most likely avenue for a laser attack would be ground based. This concept has been proven as ground based lasers have already illuminated satellites.[19] In this case, both Russia and China intend to develop this technology.[20] EMP would take the form of an indiscriminate nuclear detonation in space and HMP technology points to a space-based attack that would disrupt, corrupt or damage sensitive electronics.[21] Resiliency against these attacks is enhanced through deliberate shielding of components.

Resilience Through Redundancy and VLEO

8. If little can be done to protect against ASAT missile attacks and little data exist on the effectiveness of defences against non-kinetic direct attacks, resilience of a space-

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[17] Harrison, Johnson and Roberts, *Space Threat Assessment 2019 …*
[18] Jeff Hecht, "A “Star Wars” Sequel? the Allure of Directed Energy for Space Weapons," *Bulletin of the Atomic Scientists* 75, no. 4 (Jul 4, 2019), 162-170. doi:10.1080/00963402.2019.1628507. https://doi.org/10.1080/00963402.2019.1628507.
[19] *Ibid.*
[20] National Air & Space Intelligence Center Public Affairs Office, *Competing in Space*, 2018), 21.
[21] Harrison, Johnson and Roberts, *Space Threat Assessment 2019...*

based capability could rely on the concept of increasing the nodes within the system (network centric operations). With the network centric concept in mind, space capabilities could be made more resilient in a few ways. Without launching more satellites, the simplest way to gain redundancy is to integrate with other partner nations who possess duplicate capabilities (i.e. space surveillance). Redundancy through numbers can also be achieved by launching more RCAF satellites in space. Redundancy could also be achieved by having a backup on earth ready for launch when needed. Either of these last two strategies may soon become technologically and financially viable within the next decade thanks to the development of disrupting technologies such as CubeSats/miniature satellites and air-breathing electric propulsion satellites permitting extended operations in VLEO.

9. Increasing our own satellites in orbit may not mean launching more, but extending the life of our current satellites such as SAPPHIRE by investigating and leveraging new drone satellite technologies. Some of these technologies such as SPACE DRONE™ by *Effective Space* propose that space drones could physical interact with current satellites while in orbit to augment or prolong some of their capabilities.[22] As world leaders in space robotics with achievements such as Canadarm2, Dexter and the mobile base system, Canada and the RCAF are well poised to develop these capabilities to service our own satellites.

[22] Effective Space deploys and operates a fleet of small SPACE DRONE™ spacecraft to provide docked life- extension services for operators of geostationary satellites., *Pioneering Last-Mile Logistics in Space*.

10. The use of private sector for launch and the advent of CubeSat will drastically increase the use of space and will create opportunities for the RCAF. CubeSat launches currently cost about $100,000 and there currently exists under 3000 total satellites in orbit but they could number up to 12,000 by the mid 2020's given the private sector's ambition for mega-constellations.[23]

11. Although CubeSat and other VLEO satellites have a lifespan of months, breakthroughs in air-breathing electric propulsion opens the possibility for the RCAF to launch a higher number of persistent low cost satellites into orbit. Successful tests of an electric air-breathing engine have been carried out by the European Space Agency, who hopes this would allow satellites in VELO to remain in space for years.[24] The military and commercial potential of having satellites in these low orbits cannot be ignored. These orbits closer to the surface promise reduced launch costs, and because of the smaller distances involved, would offer an advantage in signal transmission speed compared to higher orbits. These traits would not only help the CAF but also its adversaries. Apart from these low orbit advantages, there are three main reasons state and non-state actors will invest in these CubeSat/miniature satellite capabilities; operational, resilience and low cost.

a. Operational. Given a demonstrated orbital life span of over 4 years, these smaller satellites could be tailor-made to house capabilities that meet the specific

[23] Bill Beyer and Nicholas Nelson, "Viewpoint: Space Congestion Threatens to 'Darken Skies'," https://www.nationaldefensemagazine.org/articles/2018/6/28/viewpoint-space-congestion-threatens-to-darken-skies (accessed Oct 16, 2019).
[24] "World-First Firing of Air-Breathing Electric Thruster."https://www.esa.int/Enabling_Support/Space_Engineering_Technology/World-first_firing_of_air-breathing_electric_thruster (accessed Oct 15, 2019).

needs of a named operation. Air/Space planners in a joint operations command could be more responsive to the space capability requirements of a commander. They could offer the commander a better availability and increased resilience of that capability given the possible actions of the adversaries. A possible example of operational advantage is that the current predictability of ISR orbital patterns render them vulnerable to denial. A denser constellation of smaller satellites would create much more costly denial efforts for the enemy. On a negative operational note, these smaller satellites can be harder to track and can be used as kamikazes against larger more expensive space assets.[25]

b. Resilience. These smaller satellites cannot carry some of the larger sensors required for military applications such as signal intelligence and hyperspectral imaging (for now until technology is miniaturized) however, they can complement these capabilities.[26] Lower costs makes it easier to create a constellation of satellites for redundancy, or to keep an asset on stand-by ready for launch. This concept of the "numbers games" with smaller satellites is also explored by Capt Michael Nayak, USAF, PhD, in the *Air and Space Power* journal with an attempt to provide solutions on policies aiming to disaggregate space capabilities.[27]

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[25] Michael Nayak, "Deterring Aggressive Space Actions with Cube Satellite Proximity Operations: A New Frontier in Defensive Space Control," *Air & Space Power Journal* 31, no. 4 (Dec 22, 2017), 92. https://search.proquest.com/docview/2050598005/abstract/6BBD025B6F054023PQ/1.
[26] *Ibid 94.*
[27] *Ibid 92.*

c. Low Cost. The cost for development and launch of CubeSats fall easily within ADM(Mat) purchasing power which means the CAF could independently finance some of its space capabilities without having to resort to other federal governmental or ministerial help.[28] This low cost aspect will bring advantages and disadvantages mirroring those of the rapid proliferation of small unmanned vehicles (UAV) by actors who traditionally did not have access to the air domain.

12. A major disadvantage is that VLEO may soon become relatively dense with satellites and debris as it is the focus of many new civil and military capabilities. The RCAF's current national space debris monitoring capabilities focuses solely on deep space (SAPPHIRE 6000km to 40 000km and SofS 2 looking 6000km and above).[29] Given the RCAF's current expertise in the surveillance of space, it is well positioned to invest and become a leader for the ground and/or space-based surveillance of these orbits.

CONCLUSION

13. As space debris multiplies and the weaponization of space progresses, it is crucial the RCAF ensures resilience in its space capabilities. The biggest threat to debris proliferation comes from the larger derelict objects floating in orbit and the Europeans are demonstrating that current technology can address this issue but it has yet to come to fruition in North America. Current ASAT missile technology is improving and the trend amongst superpowers is to combat it through policies of deterrence which Canada cannot contribute to due to our peaceful space policies. The RCAF's only remaining option is to

[28] (PAM) Procurement Administration Manual, *A-Pp-005-000/Ag-002,* 1.4.3.2.1.
[29] Maskell sapphire

ensure its capabilities are sufficiently integrated with those of its allies to be covered by their deterrence umbrella. Space capabilities enhancing defence and resilience should be based on Canadian strengths of robotic and space surveillance. Non-kinetic attacks can be conducted with effects that would remain under the threshold of war, but fortunately, the impact of these attacks can be mitigated by design. As the commercial satellite industry is currently being revolutionized by CubeSat/miniature satellites and soon air-breathing electric propulsion, it is imperative the RCAF leans forward in the development and use of these technologies at the peril of being left in the dust as it has with the world of UAVs.

RECOMMENDATION

14. Active and passive defences for spaced based capabilities is a highly technical field with many facets, such electronic jamming/spoofing and cyber that must be further analyzed. As for the resilience strategies discussed in this paper, it is clear that the RCAF needs to take deliberate pro-active actions to field niche, non-weaponized capabilities such as materiel research to increase passive defence, miniature satellites to provide redundancies, robotics to enhance current satellite capabilities and lead the space debris removal efforts.

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