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CANADA AND SPACE DETERRENCE:

THE SPACE SITUATIONAL AWARENESS IMPACT

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Canada

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ABSTRACT

Space capabilities are pervasive and interwoven into the fabric of modern societies. They facilitate the delivery of essential services, contribute to economy prosperity and have become an essential element of the government's activities to ensure national security and sovereignty. It is critical to ensure access to the space systems that Canada depends on. The first line of defence is space deterrence, in other words to deter potential hostile entities from interfering or damaging our most vital space capabilities. Canada already has in place many of the key space deterrence elements. This paper will explore space deterrence in the Canadian context, highlighting Canadian contributions to Space Situational Awareness (SSA), a strategic area of national interest led by National Defence in Canada. It concludes that continued involvement in SSA by the Canadian Armed Forces will positively contribute to Canada's space deterrence posture, thus allowing for continued access to critical space infrastructure.

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INTRODUCTION

Since the launch of the first man-made satellite, Sputnik, by the Soviet Union (USSR) in 1957, space capabilities have continuously been developed to support national interests. The United Sates (US) and USSR embarked on a space race over half a century years ago, but they are no longer the only ones exploiting space assets for a wide range of applications. Technology advancements in materials development, propulsion, computer miniaturization, power generation and instrument sensitivity have tremendously increased the capability of space-based platforms and sensors. They have also allowed for a significant reduction in the cost of access to space. The net result of such development in the space arena has been the significant increase in space faring nations and the multiplication of countries possessing indigenous satellite systems.

The Cold War ended 25 years ago and since then, the international geopolitical landscape has changed considerably. Americans still enjoy a significant space advantage over the rest of the world with close to half of the active satellites currently in orbit owned by the US. Russia is the next country with the most satellites in orbit, with over a fifth of what the Americans have. But there are now tens of other players in space.[1] Some are well known entities, others less so. It is estimated that there are over 170 countries with interest in a variety of space systems and 11 national organizations which possess an indigenous launch capability.[2] This state of affairs has allowed a much wider proportion of the world population to gain access to space data and

[1] As of January 2014, of the1167 total active satellites in orbit, there are 502 belonging to the US and 118 owned by the Russians, see Union of Concerned Scientists, "USC Satellite Database," last accessed 14 August 2014, http://www.ucsusa.org/nuclear_weapons_and_global_security/solutions/space-weapons/ucs-satellite-database.html.

[2] William L. Shelton, testimony in House of Representatives, *Hearing on National Defense Authorizations Act for Fiscal Year 2014 and Oversight of Previously Authorized Programs Before the Committee on Armed Services*, 113th Congress First Session, 25 April 2013, last accessed 5 June 2014, http://www.gpo.gov/fdsys/pkg/CHRG-113hhrg80769/html/CHRG-113hhrg80769.htm.

services. Space capabilities are now interwoven into the fabric of our modern society. They provide weather information and forecasting, navigation, timing for bank transactions and transportation tracking, communications services and imagery to facilitate land management to name a few. Space products and services are far reaching. They can be found in commercial applications supporting a wide-range of industries, they allow the government to provide key services such as Search and Rescue (SAR), communications to remote settlements and increase access to better medical services. The pervasiveness of space-based effects is such that modern societies have grown accustomed to them and many do not even realize the extent of their day-to-day dependence on space derived effects.

Space capabilities also grant a significant military advantage to those who have the means to exploit them. The First Gulf War was a game changer in that it demonstrated the multiplier effect space systems could bring to the battlefield. The US-led coalition military apparatus, already conventionally superior, would totally dominate the battlefield in an incredibly short time.[3] It quickly became clear that the exploitation of space-based systems integrated with army, air force and navy powers provided a decisive advantage. Space-based Intelligence, Surveillance and Reconnaissance (ISR) assets could detect the location of enemy troops and equipment, as well as terrain conditions; therefore providing a safe mean to collect information critical to the commanders on the ground (as opposed to ISR done from air platforms, which could become targets for enemy's surface to air weapon systems). Voice and data exchanges between troops went unhampered because of the availability of satellite communications over the theatre of

[3] Department of Defense, *Desert Storm "Hot Wash" 12-13 July 1991*, last accessed 9 August 2014, http://www2.gwu.edu/~nsarchiv/NSAEBB/NSAEBB39/document7.pdf.

operations. The adversary was not able to gain a military advantage without similar access to space-based capabilities, and was quickly overwhelmed.

Since then, the power multiplier effect afforded by satellite systems has remained. Hence many countries have developed various operational space capabilities. The space environment is now congested, contested and competitive.[4] It is congested due to an increasing number of objects in space, contested because there are more and more actors wanting to ensure their access to the space domain, and competitive because of the increasing role played by commercial entities in the space area. Furthermore, the proliferation of actors in space has changed the geopolitical landscape. Although the US remain the most powerful military space power in the world; there are now several nations with capabilities that could potentially challenge this supremacy. The American space advantage and their concurrent dependence on space systems expose a vulnerability that could be exploited by hostile entities with the ability and intent to do so. Satellites systems are technologically complex. They are designed to operate in the harsh environment of space, but not to defend themselves against aggression. The hefty cost of launching anything into space leads designers to build spacecraft to meet very narrow mission requirements with the least amount of margin acceptable. Incorporating effective and usually weighty defensive mechanisms on board would be cost prohibitive in most cases. Hence, modern space systems remain vulnerable to attack, either from kinetic anti-satellite (ASAT) systems or less physically damaging methods such as jamming.

[4] Department of Defense and Office of the Director of National Intelligence, *National Security Space Strategy* (Washington, DC: 2011), last updated 20 February 2014, http://www.defense.gov/home/features/2011/0111_nsss/docs/NationalSecuritySpaceStrategyUnclassifiedSummary_Jan2011.pdf; United Nations General Assembly, *Outer Space Increasingly 'Congested, Contested and Competitive'*, sixty-eight General Assembly First Committee 17th Meeting, last accessed 20 February 2014, http://www.un.org/News/Press/docs/2013/gadis3487.doc.htm.

Accepting that modern societies are highly dependent on space systems to maintain their standard of living and for national security despite those systems vulnerabilities, how to ensure that access to space capabilities can be maintained? An effective space deterrence posture could play a vital role. The US, with their overwhelming reliance on space-based capabilities have in recent years increasingly highlighted the importance of space deterrence. Canada is also highly dependent on space systems, both indigenous and allied. What does space deterrence mean in the Canadian context? Why is it relevant?

In the last decades, the Government of Canada (GoC) and National Defence have invested in various space capabilities in order to deliver the required space effects for Canadians and the Canadian Armed Forces (CAF). Those include undertakings in satellite communications, space-based ISR, SAR capabilities; and position, navigation and timing. Another significant space strategic area has been involvement in Space Situational Awareness (SSA). In broad terms, SSA refers to knowing what is happening in space. With space becoming increasingly congested, contested and competitive, SSA has become a critical precaution that facilitates continued safe operations in the space domain. Furthermore, the US has deemed SSA essential to successful space deterrence.[5] What does it mean for Canada? Could SSA play a role in Canadian space deterrence? This is what this research paper will examine. **It will show that continued involvement in SSA by the CAF will positively contribute to Canada's space deterrence posture**.

To frame the discussion, several aspects will be explored. The first chapter will provide a space governance overview considering both the international and domestic contexts. The second

[5] House of Representatives, *Hearing on National Defense Authorizations Act for Fiscal Year 2014 and Oversight of Previously Authorized Programs Before the Committee on Armed Services*, …

chapter will explore space deterrence and Chapter 3 will discuss the Canada-US relationship as it applies to space, focusing on the defence front. Threats to space systems will be discussed in Chapter 4. In Chapter 5, SSA will be defined in details followed by a description of the CAF involvement with SSA providing a historic of previous investments and potential future activities in Chapter 6. Chapter 7 will discuss how SSA can support space deterrence. Finally, Chapter 8 will present several arguments on why pursuing investments in SSA would positively contribute to Canada's space deterrence posture.

1. GOVERNANCE

Before addressing space deterrence and SSA, it is useful to discuss the existing space governance. Over fifty years ago, Russia launched Sputnik, the first man-made satellite, which was followed a few months later by the American Explorer-1 spacecraft in 1958. Subsequently, Russians and Americans would embark on a space race to the moon. The space rivalry extended to the military realm. For example, both the US and the USSR had ASAT programs and tested their capabilities early on. It soon became apparent that the damage caused by such weapon was significant and the aftermath effects were indiscriminate of the country of origin. For example, in 1962 the US detonated a nuclear weapon in space disabling six US and foreign satellites[6], while experimental kinetic hit by direct ascent systems by both countries created large amount of debris that could have impacted any satellite indiscriminately (see Appendix 1). It rapidly became apparent that a mechanism needed to be established to restrain a potential conflict to the surface of the Earth and to prevent the weaponization of space. Hence the Partial Test Ban

[6] Phil Plait, "The 50th Anniversary of Starfish Prime: The Nuke that Shook the World," *Discover Magazine*, 9 July 2012, last accessed 9 August 2014, http://blogs.discovermagazine.com/badastronomy/2012/07/09/the-50th-anniversary-of-starfish-prime-the-nuke-that-shook-the-world/.

Treaty (initially signed by the US, USSR and United Kingdom(UK)), which would ban the testing of nuclear weapons in the atmosphere, outer space or at sea, was established in 1963. [7] This agreement was followed by the more comprehensive Outer Space Treaty (OST), which entered into force in 1967.[8] To this day, this international framework continues to be relevant and the OST remains the only treaty preventing the deployment of nuclear weapons and other weapons of mass destruction in outer space. [9] Aside from the OST, there exists four other space-related multilateral treaties related to the rescue and return of astronauts and spacecraft[10], the international liability for space activities[11], spacecraft registration obligations[12], and the activities on the moon and other celestial bodies[13]. Together, they form the main body of international space law.

Aside from international treaties, there has been a trend towards putting in place codes of conducts and best practices agreements. The rationale being that those types of arrangements are less restrictive on the participants while encouraging them to behave as responsible space actors.

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[7] United Nations General Assembly, *Treaty Banning Nuclear Weapon Tests in the Atmosphere, in Outer Space and under Water*, last accessed 20 February 2014, http://www.un.org/disarmament/WMD/Nuclear/pdf/Partial_Ban_Treaty.pdf.

[8] United Nations General Assembly, "Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies," in United Nations General Assembly, *Treaties and Principles on Outer Space* (New-York, 2002):3-7, last accessed 5 June 2014, http://www.oosa.unvienna.org/pdf/publications/STSPACE11E.pdf.

[9] Nayef R.F Al-Rhodam, *Meta-Geopolitics of Outer Space: An Analysis of Space Power, Security and Governance* (Hampshire: Palgrave MacMillan, 2012): 78-79.

[10] United Nations General Assembly, "The Agreement on the Rescue of Astronauts, the Return of Astronauts and The Return of Objects Launched into Outer Space," in United Nations General Assembly, *Treaties and Principles on Outer Space* (New-York, 2002):8-10, last accessed 5 June 2014, http://www.oosa.unvienna.org/pdf/publications/STSPACE11E.pdf.

[11] United Nations General Assembly, "Convention on International Liability for Damage Caused by Space Objects," in United Nations General Assembly, *Treaties and Principles on Outer Space* (New-York, 2002):11-18, last accessed 5 June 2014, http://www.oosa.unvienna.org/pdf/publications/STSPACE11E.pdf

[12] United Nations General Assembly, "Convention on Registration of Objects Launched into Outer Space," in United Nations General Assembly, *Treaties and Principles on Outer Space* (New-York, 2002):19-22, last accessed 5 June 2014, http://www.oosa.unvienna.org/pdf/publications/STSPACE11E.pdf.

[13] United Nations General Assembly, "Agreement Governing the Activities of States on the Moon and Other Celestial Bodies," in United Nations General Assembly, *Treaties and Principles on Outer Space* (New-York, 2002):23-30, last accessed 5 June 2014, http://www.oosa.unvienna.org/pdf/publications/STSPACE11E.pdf.

Confidence-Building Measures (CBMs) do not focus on specific capabilities, but on the intent or the perception of the intent when using those capabilities.[14] Canada proposed a 3D model (Declare what you will do, Do what you had declared, Demonstrate that you did what you declared). In this sort of cooperative monitoring, "the onus is on compliance demonstration" and it "could be less adversarial than challenge inspections or invitations to observers".[15] Under the United Nation (UN) Committee on Peaceful Uses of Outer Space (COPUOS) and Conference on Disarmament (CD), various agreements have been suggested. Examples include the Code of Conduct proposed through the European Union (EU). There is also the Prevention of the Placement of Weapons in Outer Space draft treaty (PPWT) proposed and favoured by Russia and China, but this is not seen as palatable by the US due to both its restrictive nature and the fact that it does not prohibit tests that could generate debris.[16] Furthermore, Canada, which has had a long-standing policy against the weaponization of space, submitted a working paper to the CD recommending three rules for a future legally binding agreement that would address security concerns in outer space while preventing the placement of weapons of mass destruction.[17] No consensus on a new international space agreement has been reached yet, although discussions continue.

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[14] Philip Baines, "The Potential for Outer Space CBMs," In United Nations Institute for Disarmement Research, *Building the Architecture for Sustainable Space Security - Conference Report 30-31 March 2006* (Vienna, 2006):16-17.

[15] Philip Baines, "The Potential for Outer Space CBMs,"…, 16-17.

[16] United Nations Conference on Disarmament, *Proposed Prevention of an Arms Race in Outer Space (PAROS) Treaty*, Center for Nonproliferation Studies, 12 March 2012, last accessed 1 June 2014, http://cns.miis.edu/inventory/pdfs/paros.pdf; Nancy Gallaguer, "Space Governance and International Cooperation," Center for International and Security Studies at Maryland (University of Maryland, 2010): 9, last accessed: 20 February 2014, http://www.cissm.umd.edu/papers/files/space_governance_and_international_cooperation.pdf.

[17] United Nations Conference on Disarmament, "*CD Working Paper: On the Merits of Certain Drafts Transparency and Confidence-Building Measures and Treaty Proposals for Space Security*," last accessed 20 February 2014, http://daccess-dds-ny.un.org/doc/UNDOC/GEN/G09/615/92/PDF/G0961592.pdf?OpenElement.

An area that has experienced better success is with respect to debris mitigation. As space data and services become increasingly pervasive in everyone's day-to-day live, national entities realize that space as a global common needs to be protected. One way to protect the space environment is through debris mitigation mechanisms. Space faring states have taken steps to establish internationally acceptable best practices with respect to debris mitigation. The UN COPUOS through the Inter-Agency Space Debris Coordination (IADC) committee has helped to standardize best practices with the development of a set of guidelines established in 2007. Examples of such rules include the deorbiting of Low Earth Orbit (LEO) satellites within 25 years after launch and pushing Geosynchronous Earth Orbit (GEO) spacecraft into graveyard orbits.[18] The guidelines are voluntary and because the norms involve additional costs due to an added set of requirements that needs to be met, compliance and national enforcement fluctuate.[19]

Another international agreement is the EU-led Code of Conduct for Outer Space Activities. This document reinforces the elements of the OST and highlights the requirement to maintain the peaceful use of space, minimize the generation of long-lasting debris, and the need to refrain from damaging space assets unless it is for overbearing security reasons.[20] Similarly to the IADC

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[18] A graveyard orbit is one that is used to remove GEO spacecraft at the end of their operational life from the orbital position they hold. Left-over propellant within the spacecraft is used to push it to a higher altitude often called a 'supersynchronous' orbit in order to avoid a potential collision with active satellites in GEO and allow for a subsequent satellite to be launched into that position. There are acceptable guidelines provided by the IADC to calculate the appropriate graveyard orbit (see United Nations Committee on the Peaceful Uses of Outer Space. *Space Debris Mitigation Guidelines*. Last accessed 9 Aug 2014. http://orbitaldebris.jsc.nasa.gov/library/Space%20Debris%20Mitigation%20Guidelines_COPUOS.pdf).

[19] Nancy Gallaguer, "International Cooperation and Space Governance Strategy," In *Space Strategy in the 21st Century: Theory and Policy,* ed. by Eligar Sadeh (New-York: Routledge, 2013):56-57; Nancy Gallaguer, "Space Governance and International Cooperation,"…, 5;

[20] United Nations Institute for Disarmament Research, *Space Security Conference 2012 Report*, 3, last accessed 20 February 2014, http://www.unidir.org/files/publications/pdfs/space-security-2012-en-306.pdf.

guidelines, the language in the Code of Conduct is not specific as to how the norms proposed are to be followed.[21]

Although there have been progress, more work is required in this area. It has been suggested that instead of focusing on preventing negative effects, these agreements should focus on the positive outcomes they could bring through CBMs, for example. By getting buy-in from the participants on the positive results brought by signing an agreement such as better sharing of information, and moving away from wording that could be seen as self-serving, better success could be obtained. The more buy-in one could get, the more respective national security could be improved and the more secure it would make the space environment. Even if there are an increasing number of non-state actors in space, by having a significant amount of countries signing an agreement, potential hostile groups could be deterred from acting due to the possible repercussions. If the level of threats to space systems could be decreased, then improved global security would ensue.[22]

The dual nature of space technologies, in that they can be used for both civilian and military applications, brings many challenges to international collaboration. Space assets that bring great civilian benefits such as for banking, safety of navigation, environment monitoring can also serve defense and security applications. Hence who should be directing and overseeing space governance? SSA and navigation and positioning systems have traditionally been led by the military (i.e.: US Space Surveillance Network, Global Positioning System (GPS), and Russian GLONASS). Satellite communications are largely led by commercial entities (i.e.: Telesat and Intelsat) while weather and space exploration fall to government civilian agencies (i.e.: US

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[21] Nancy Gallaguer, "International Cooperation and Space Governance Strategy,"…, 57.

[22] Nancy Gallaguer, "Space Governance and International Cooperation,"...

National Oceanic and Atmospheric Administration (NOAA), Natural Resource Canada and EUMETSAT for weather, and US National Aeronautics and Space Administration (NASA), Canadian Space Agency (CSA), and European Space Agency (ESA) for space exploration). Coordination of the radio frequency spectrum is overseen by the UN International Telecommunications Union (ITU).[23] Current international agreements are not sufficient to guarantee the security and sustainability of the space environment and there is no one overarching international body responsible for space cooperation.[24] The UN COPUOS mostly handles space aspects related to the peaceful use of space in the civil realm while the CD is favoured for military issues. It has been argued that a more holistic approach to addressing space issues is required. An organization or board empowered with an internationally accepted mandate and legal authority would present a better option to ensure the stability and security of the space common.[25] In 2012, the first meeting of the UN COPUOS Working Group on Long-Term Sustainability of Space Activities and the UN Group of Governmental Experts on transparency and CBMs in outer space activities were held, which are expected to advance the dialogue.[26]

Despite space security concerns relevant to all space actors and the recognized need for more regulations, a consensus on a more comprehensive treaty reflective of the current space environment has not been reached yet. The OST remains valid, but it was created in the Cold War era. With the proliferation of space actors in the last few years, several aspects of the OST

[23] United Nations International Telecommunications Union, *Constitution of the International Telecommunications Union*, last accessed 9 August 2014, http://www.itu.int/dms_pub/itu-s/oth/02/09/s02090000115201pdfe.pdf.

[24] Nayef R.F Al-Rhodam, *Meta-Geopolitics of Outer Space: An Analysis of Space Power, Security and Governance*, …, 100.

[25] Nancy Gallaguer, "International Cooperation and Space Governance Strategy,"…, 69.

[26] Project Ploushares, *Space Security Index 2013*, ed. by Cesar Jaramillo (Kitchener: Pandora Print Shop, 2013):21, last accessed 20 February 2014, http://swfound.org/media/121668/SSI_Full_Report_2013.pdf.

need to be refined and new ones addressed.[27] With the main goal to keep space a sanctuary available for everyone to use now and in the future, it is important that international discussions preventing the weaponization of space continues. It is also essential that any conflict in space be deterred to preserve the space common safety and sustainability. Continuing the dialogue on relevant international governance framework can support a deterrence posture as will be discussed below.

2. SPACE DETERRENCE

In recent years, there has been reference to the concept of space deterrence in US literature, although there has not been much discussion on a Canadian space deterrence posture and why it is important to have one.[28] What is space deterrence? Why is it relevant to Canada and the CAF? This chapter will strive to define space deterrence providing a Canadian context and concluding with the assumption that Canada does hold a spaced deterrence position, albeit not one that has been clearly articulated yet.

According to the Oxford dictionary, deterrence comes from the noun deterrent, which is defined as a "thing that discourages or is intended to discourage someone from doing something". Another definition is: "Measures taken by a state or an alliance of states to prevent hostile action by another state".[29] Encyclopedia America is even more specific and states that deterrence is a *military strategy under which one power uses the threat of reprisal effectively to preclude an*

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[27] United Nations Institute for Disarmament Research, *Space Security Conference 2012 Report…*, 2.
[28] Discussion on space deterrence in RAND Corporation, *Deterrence and First-Strike Stability in Space: A Preliminary Assessment*, Project Air Force, 2010, last accessed 20 February 2014, http://www.rand.org/content/dam/rand/pubs/monographs/2010/RAND_MG916.pdf.
[29] "Deterrence," last accessed 30 Mar 14, http://www.thefreedictionary.com/deterrence.

attack from an adversary power.[30] For this paper, the US definition of deterrence will be used: "The prevention from action by fear of the consequences. Deterrence is a state of mind brought about by the existence of a credible threat of unacceptable counteraction."[31] Ultimately, it is understood that a state or group looking at attacking another will select the course of action that is expected to best serve their interest and values.[32]

The deterrence concept is often referred to in the context of nuclear powers. It stems from the Cold War era when both the US and USSR possessed nuclear weapons and could potentially use them against each other, in other words the mutually assured destruction military strategy. The premise of deterrence is founded on two key principles. The first is that the state has the necessary capability to inflict significant damage if it is attacked; the second is related to the will to act. During the Cold War, both nations had proven that they possessed nuclear weapons and had the ability to deliver them into enemy territory. It was also understood that if a nuclear attack was launched, the detection technology was such that the attack could be sensed in time for the other to also release nuclear weapons. Escalation of hostilities would ensue where more nuclear attacks would be made, in which case mutual destruction was almost guaranteed. As mentioned above, the ability to retaliate is only one part of the equation for deterrence to be successful, the other is related to the will to retaliate in case of an attack. During the Cold War, there was tacit understanding that Washington and Moscow would strike back if one were to attack the other.

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[30] "deterrence." *Encyclopaedia Britannica. Encyclopaedia Britannica Online Academic Edition*, Encyclopædia Britannica Inc., 2014, last accessed 30 Mar 2014, http://www.britannica.com/EBchecked/topic/159558/deterrence.

[31] Department of Defense, *Joint Publication 1-02, Dictionary of Military and Associated* Terms, last updated 15 June 2014, http://www.dtic.mil/doctrine/new_pubs/jp1_02.pdf.

[32] James D. Rendleman, "Strategy for Space Assurance," in *Space Strategy in the 21st Century: Theory and Policy,* ed. by Eligar Sadeh (New-York: Routledge, 2013), 85.

The means of deterrence were understood and the main objective was to prevent nuclear war; hence, nuclear deterrence succeeded.[33]

Since then, the geopolitical situation has become more complex. There are now a growing number of emerging military powers striving for greater recognition, as well as an increasing amount of non-state actors posing asymmetric threats. Traditional deterrence thinking thus needs to be expanded to include non-nuclear capabilities, such as in the air, cyber and space domains, as well as softer responses such as sanctions, diplomatic isolation, denial of cooperation and membership in international organizations, which can induce significant factors to consider in hostile entities' decision-making process.[34]

The next question is whether the nuclear deterrence analogy can be extended to space deterrence. On the surface, it might appear so. Looking at the US and Soviet Union again, they both possess a significant number of space assets.[35] They have also demonstrated in the past a kinetic ASAT capability, covering the first aspect of a deterrence strategy.[36] Now, would any of them be willing to use this capability against each other? This is a lot more questionable. A kinetic attack on a satellite would create thousands of debris objects, which would then threaten other spacecraft indiscriminately. With the current international dialogue on debris mitigation involving both countries, it is doubtful that either would retaliate with a similar attack. One could

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[33] Adam Lowther, *Deterrence: Rising Powers, Rogue regimes and Terrorism in the Twenty-First Century* (New-York: Palgrave MacMillan, 2012), 1-2, 4.

[34] William A. Chambers, "Foreword," in Adam Lowther, *Deterrence: Rising Powers, Rogue regimes, and Terrorism in the Twenty-First Century* (New-York: Palgrave MacMillan, 2012), XII-XIII.

[35] As of 2013, the US possess 107 active military satellites while Russia has 58, see The International Institute for Strategic Studies, *The Military Balance 2013*, ed. by James Hackett (London: Routledge, March 2013), 72, 226.

[36] See Appendix 1 and Michael Krepon, "Responding to China's Counter-space Capabilities," Stimson Centre, 30 January 2014, 1, last accessed 20 February 2014, http://www.stimson.org/spotlight/responding-to-chinas-counter-space-capabilities/.

argue that both countries would shy away from launching the first ASAT weapon to begin with. The nuclear deterrence model is therefore not directly applicable to space deterrence.

That being said, space deterrence has still been successful if one is to look at the same players. Although it seemed early on that war in space was inescapable, it has not materialized yet. Both countries also refrained from placing weapons in orbit abiding to the OST despite significant political tensions. Through this fine balance, space warfare has been avoided and space deterrence has succeeded despite a lack of will to attack, then and now. This state of affairs can be explained by several factors. First, both Washington and Moscow's leadership understand that space warfare would cause the escalation of hostilities in other domains and that satellite launchers (which they both have) can quickly be re-assigned to deliver offensive military payloads. Finally, space systems are inherently vulnerable as will be discussed at Chapter 4. In other words, catastrophic damage is easily inflicted hence the reserve of both countries in inflicting it for fear of escalation.[37] Ultimately, space warfare has not been seen as serving neither country's best interests up to now.

In the last four decades the US and Russia have developed tacit understanding of their respective political stratagems and red lines with respect to nuclear weapons and space. Despite different ideologies, they have been successful in achieving a balance that has sustained the availability and security of the space environment.[38] As America's closest neighbour, this stability between the two military powers has greatly benefited Canada.

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[37] Michael Krepon, "Responding to China's Counter-space Capabilities,"…, 1.

[38] Michael Krepon, "Waiting for Trouble," *Space News*, 31 March 2014, last accessed 5 June 2014, http://www.spacenews.com/article/opinion/40055waiting-for-trouble.

What if one was to look at an emerging space power such as China? The situation with China is different on several fronts. First, despite its immense advancement in the economic and technological realms in the last few years, China remains a developing nation. It has high aspiration to become a great power, but it has not achieved this status yet. Second, there are no history of negotiation and/or cooperation between Washington and Beijing in the space domain, aside from the work through the UN CD. Civilian space cooperation has historically been easier, as the world has seen with the Apollo-Soyuz docking during the Cold War and more recently with the ISS. However in the case of China, the interrelations between their civilian and military programs have created discomfort. Furthermore, NASA was banned from working with China as a result of the Chinese 2007 ASAT test as it made the US doubt Beijing's intent.[39] The situation is similar in the research and development realm. Even during the Cold War, US and Soviet laboratory officials frequently interacted (albeit with many safeguards), which allowed a certain level of cooperation despite heightened tensions. In the case of China, researchers' exchanges have been restricted especially since 1999 due to nuclear espionage concerns.[40] There are no established communications channels between the US and China with respect to space, which has created many uncertainties as to Beijing's intentions and therefore made more complex the deterrence calculus.[41]

Space deterrence is further complicated by the fact that the range of space actors with potentially hostile intent is no longer limited to national entities. Despite the fact that there are issues with China's position and lack of transparency, it remains a sovereign country which aspires to be a

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[39] Joshua Philipp, "US Alert to China Space Threat" *Epoch Times*, 7 February 2014, last accessed 5 June 2014, http://www.theepochtimes.com/n3/493785-us-alert-to-china-space-threat/#?photo=2&_suid=139386667079003522081204420897.

[40] Michael Krepon, "Waiting for Trouble,"…

[41] Michael Krepon, "Responding to China's Counter-space Capabilities,"…, 1.

greater world power. With advances made in smaller satellite development and the globalized markets, it is now easier for non-state actors to access space technologies and/or the means to interfere with friendly space capabilities. These organizations would most likely not have similar ideology and an understanding of what far reaching impact their hostile actions could have. They are also harder to track, reason with and dissuade, which further increases the space deterrence challenge.[42] It has also been argued that not all hostile non-state actors might be deterred due to different ideologies and that they most often operate outside the law of conflict.[43]

That brings us to the next question: is the possession of a kinetic ASAT capability essential for effective space deterrence? As was observed during the Cold War, one of the main reasons that nuclear deterrence worked between the US and the Soviet Union was because they both had developed and successfully tested the technology for the delivery of nuclear warheads. Without this, the balance of power would have most likely rapidly shifted to the one country with this capability. With space deterrence, the answer points to the opposite. It is not that the possession of demonstrated ASAT interceptors and launch capability would not help deterrence, but that to achieve space deterrence, this ASAT technology is not a mandatory requirement. Latent technologies exist which could cause severe damage to space assets and infrastructure, such as jammers, lasers and cyber infiltrations. Hence the development of kinetic ASAT systems might not be the most effective way to achieve space deterrence.[44] It could also be argued that the

[42] Toffler Associates, *Protecting our Space Capabilities: Securing the Future* (Manchester, MA: 2008), 8, last accessed 9 June 2014, http://www.toffler.com/assets/1/6/2008_-_Protecting_Our_Space_Capabilities_-_Securing_the_Future_080723v2.pdf.

[43] Adam Lowther, *Deterrence: Rising Powers, Rogue regimes and Terrorism in the Twenty-First Century* …, 4.

[44] Michael Krepon, “Responding to China’s Counter-space Capabilities,” …; Michael Krepon, “Promoting National and Economic Security Interests in Space,” in Department of Defense, *Joint Hearing on the People’s Republic of China’s Counterpace Program and the Implications for U.S. National* , House Armed Services

development of such systems could encourage other actors to build similar programs in order to protect their space systems, which could then escalate into an ASAT arms race. Other means to strengthen space deterrence are proposed below.

The main goal of space deterrence is to send the right messages to persuade hostile entities that damaging the space systems we depend on would not be in their best interest as it would result in a response that would bring worse consequences then if other courses of actions would be chosen.[45] Ways to boost a space deterrence posture include developing capabilities to operate in a degraded environment, for example when access to space data and services is limited, intermittent or outright unavailable due to hostile interference. By developing corresponding doctrine and testing these capabilities through various exercises, it would demonstrate resilience from mal intent and reduce the attractiveness of attacking space systems by potential adversaries as independence from those capabilities would have been proven.[46]

Aside from looking at non-space means to discourage foes from targeting space systems, leveraging other assets would provide another solution. By cooperating with commercial and civil entities on their respective space platforms, such as through arrangements (Memorandum of Understanding (MOUs), Project Arrangements (PAs), etc.), service contracts (in the case of commercial imagery or satellite communications for example) or putting hosted payload on

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Subcommittee on Strategic Forces, 28 Jan l accessed 20 February 2014, http://docs.house.gov/meetings/AS/AS29/20140128/101680/HHRG-113-AS29-Wstate-KreponM-20140128.pdf.

[45] James D. Rendleman, "Strategy for Space Assurance," in *Space Strategy in the 21st Century: Theory and Policy…*, 85; Susan Helms, "Schriever Wargame 2010: Thoughts on Deterrence in the Non-Kinetic Domain," *Air Force Space Command High Frontier*, vol. 7, 1 (November 2010), 13; RAND Corporation, *Deterrence and First-Strike Stability in Space: A Preliminary Assessment …*, 24.

[46] C. Robert. Kehler, "Implementing the National Security Space Strategy," *Milsat Magazine*, April 2012, last accessed 20 February 2014, http://milsatmagazine.com/story.php?number=1514333390.

someone else's platform, the space capacity is disaggregated [47] making it harder for hostile actors to interfere.[48] It also increases the political and escalatory risks as those systems are used for many entities, hence deterring disruption.[49] Another way to enhance space deterrence is to increase international partnerships. This would reduce the allure of attacking a space system (unless one was looking at negatively impacting all of the countries involved in that partnership), by risking upsetting other partners and hence facing retaliation by multiple nations. For example, Canada has bought into the US Wideband Global Satcom (WGS) constellation along with Denmark, Luxemburg, the Netherland and New Zealand.[50] Entering into a cooperative agreement with a nation like China could also increase space deterrence. Both states would then invest and benefit from the space capability and hence the risk would be reduced that either would be willing to disrupt the capability.

Increasing disaggregation of space capabilities would also serve to increase resilience to attacks. In other words, dispersing space capabilities across multiple platforms would increase the robustness of the system. It would ensure that even if one spacecraft was rendered useless, the space capability would remain through the other satellites. For example, a study highlighted that for the US GPS constellation to significantly reduce its accuracy, over one third would have to be non-functioning.[51] Building smaller satellites that could be replaced quickly would also be

[47] Space disaggregation can be defined as: "The dispersion of space-based missions, functions or sensors across multiple systems spanning one or more orbital plane, platform, host or domain." See Department of Defense, *Resiliency and Disaggregated Space Architecture*, Air Force Space Command White Paper (Washington, DC: 2013), last accessed 5 June 2014, http://www.afspc.af.mil/shared/media/document/AFD-130821-034.pdf.

[48] C. Robert. Kehler, "Implementing the National Security Space Strategy,"…

[49] RAND Corporation, *Deterrence and First-Strike Stability in Space: A Preliminary Assessment …*, xi.

[50] Joakim Kasper Oestergaard, "About the WGS Program," *Barr Group Aerospace*, 27 June 2014, last accessed 9 August 2014, http://www.bga-aeroweb.com/Defense/Wideband-Global-SATCOM.html.

[51] Toffler Associates, *Protecting our Space Capabilities: Securing the Future* …, 10.

effective. Although each of these spacecraft would most likely have a restricted ability compared to the full scale version, it could be replaced more quickly and prevent a total capability loss.

Space deterrence can also be greatly strengthened through diplomatic means. Nuclear deterrence succeeded through bi-lateral treaties, but space deterrence is more complex. With so many space capabilities intertwined in the fabric of modern societies, it would be near impossible to curtail their use solely for the purpose of avoiding space warfare.[52] However, there are still diplomatic ways to improve the space deterrence posture with the development of rules of the road and international acceptable behaviours. There exist codes of conduct for navies, armies and air forces, hence similar agreements could be put in place to cover defence space activities.[53]

Another aspect to consider is that the key elements of a space deterrence position need to be developed, credible and advertised before the start of hostilities if they have any chance of being effective. Due to the high dependence on space assets, the main objective of space deterrence should be to deter any hostile act, either kinetic or non-kinetic, on space systems of interest.[54] Threatening to retaliate with an appropriate response could include using conventional means, not necessarily with ASAT systems. The complexity of the space environment and the proliferating number of space actors makes it increasingly important, although it also presents a significant challenge as each adversary can see the geopolitical world through a different lens. As Major-General Susan Helms, former US Strategic Command (USSTRATCOM) Director of Plans and Policy expressed in 2010: "Deterrence is not static; effective deterrence strategies will morph under conditions of crisis, and the level of uncertainty about your adversary's decision

[52] Richard Garwin, "Taming Antisatellite and Space Weapons," *Bulletin of the Atomic Scientists*, 29 May 2007, last accessed 5 June 2014, http://thebulletin.org/taming-antisatellite-and-space-weapons.
[53] Michael Krepon, "Responding to China's Counter-space Capabilities," …
[54] Susan Helms, "Schriever Wargame 2010: Thoughts on Deterrence in the Non-Kinetic Domain,"…, 12.

process must be actively tracked and accounted for, or else you risk serious miscalculation and unexpected deterrence failure."[55] A combination of general red lines and more specific statements would probably be most appropriate in considering space deterrence. For example, it is understood that a kinetic ASAT weapon launched at another country's space asset would be considered an act of war, and would hence result in significant retaliation. For reversible threats, there is no clear formula as to what reprisal would be imposed for malevolent disruptions.[56] A level of interference with Western space systems has been experienced and tolerated in past operations.[57] This is not to say that it should continue, but that it should help devise a more explicit space deterrence posture.

Many of the elements supporting space deterrence mentioned above are already part of the Canadian efforts. For instance, the CAF is involved in the Navigation Warfare (NAVWAR) program exploring ways to operate in a GPS degraded environment hence demonstrating a level of resilience to GPS jamming.[58] In addition, Canada participates in a variety of space related international MOUs and arrangements. Many of those are with the US hence increasing the space deterrent factor. In other words, a potential hostile actor wanting to interfere with or threatened Canada's access to space would also have to take into account the American military power in its attack cost-benefit calculus before taking action. Moreover, Canada has been investing in small satellite technology development as well as participating in international forums to study the military utility of smaller satellites that would be more cost effective and

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[55] Susan Helms, "Schriever Wargame 2010: Thoughts on Deterrence in the Non-Kinetic Domain,"…, 13.

[56] For a discussion on redlines applicable to the space environment, see Matthew Kleiman, and Sonia McNeil, "Red Lines in Outer Space," *The Space Review*, 5 March 2012, last accessed 9 August 2014, http://www.thespacereview.com/article/2038/1.

[57] Susan Helms, "Schriever Wargame 2010: Thoughts on Deterrence in the Non-Kinetic Domain,"…, 14.

[58] See Chapter 4 for more details.

support the disaggregation of space capabilities, which would make them more resilient to space attacks. Finally, Ottawa has been participating in UN-led international committees on space security, supporting the efforts for enhancing space security and sustainability. Most notably with the release of the Canadian working paper on the merits of transparency and CBMs at the CD in 2009, Canada is recognized as a “serious player on space security”.[59] In summary, despite not being involved in a kinetic ASAT program, Canada has taken steps to establish a space deterrence position. It could be argued that this situation is due to a favourable arrangement of circumstances, with the main reason attributable to its small space program and hence extremely high reliance on commercial and allied space systems. Nonetheless, the fact remains that the foundation for space deterrence exists.

Although a Canadian space deterrence position has not been articulated yet, the CAF has started to look at space deterrence. For example, the CAF has been participating in the US Air Force Space Command-led Schriever Wargame series where the space deterrence concept is being explored, the draft 2014 National Defence Space Policy makes mention of space deterrence and Colonel André Dupuis, Acting Director General Space has also highlighted its importance in 2014.[60] For the purpose of this paper, it is assumed that because Canada already has in place many elements of space deterrence (active participation in UN space related forums and in international agreements, involvement in NAVWAR, CAF involvement in relevant exercises and R&D space investment), Canada holds an informal space deterrence posture.

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[59] Michael Krepon, “Canada Reclaims its Space,” *Arms Control Wonk*, 14 May 2010, last accessed 20 February 2014, http://krepon.armscontrolwonk.com/archive/2729/canada-reclaims-its-space.

[60] André Dupuis, personal conversation, 9 May 2014.

A critical aspect of space deterrence has not been discussed up to now: SSA. For any space deterrence posture to be effective, it must be possible to identify the originator of a hostile act or whether the interference is non-intentional. The ability to rightfully attribute an attack then allows for the right response to be exercised. It was straightforward to do during the Cold War with respect to nuclear weapons as the detection technology allowed the location of launches to be identified and there were very few players. These days, with tens of space actors, the proliferation of space technologies and a variety of ways to interfere with space systems, the ability to timely and correctly identify the perpetrator is essential. This is where SSA becomes critical, which will be discussed in Chapters 5 and 6. But first, the unique Canada-US relationship in the space domain will be examined as this cooperation has significant implications for Canada's space deterrence posture.

3. CANADA AND THE US

When discussing space involvement by Canada and the CAF, and specifically the concept of space deterrence, it is important to highlight Canada's close relationship with the US as this has been a key driver of its defence implication in space. This chapter will provide a brief history of Canada-US space engagements and draw attention to ongoing mutual activities.

Canada was the third country to develop and launch[61] a national satellite in space with Alouette in 1962. Alouette was developed by a team under Dr. John H. Chapman at the Defence Research Telecommunications Establishment in Ottawa, Ontario to study the ionosphere. This first

[61] The US provided the launcher for Alouette.

spacecraft was followed by Alouette 2 in 1965 and ISIS in 1969.[62] Canada's close cooperation with its Southern neighbour also extended to the space arena. Canadian defense experts worked with their American counterparts on several space defence initiatives in areas such as active missile defence and space control. It is only towards the end of the 1960's that support for these programs was halted. Subsequent defence efforts focused on the exploitation of space assets for military purposes highly leveraging allied systems, mainly from the US. In addition, there were many government sponsored studies on the upper atmosphere and launch systems, which resulted in the development of the indigenous Black Brant rocket and the launch facility in Churchill, MA.[63] In 1963, a comprehensive space defence program was approved which included research and development on techniques and technologies for anti-satellite systems with a focus on co-orbital approaches. Despite the significant progresses made, this program would die down a few years later with the change in Canadian political leadership and international geopolitical situation.[64]

The nature of the space environment, in which there is no boundary and objects in orbit continuously rotate around the Earth, rapidly emphasized the strategic advantage space assets could have for national security. For example, optical sensors integrated on space platforms could provide routine coverage of enemy territory or other areas of interest and communications could be secured anywhere in the world through satellite communications. It was also understood that a country that had the technology to put a satellite in space also had the capability to launch

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[62] David Emerson, Jacques Roy, Sandra Pupatello, and Jim Quick, *Reaching Higher: Canada's Interests and Future in Space* (Ottawa: Publishing and Depositary Services, 2012): 11, last accessed 20 February 2014, http://aerospacereview.ca/eic/site/060.nsf/vwapj/Space-e-online.pdf/$file/Space-e-online.pdf.

[63] Andrew Godefroy, "The Intangible Defence: Canada's Militarization and Weaponization of Space," In *The Canadian Way of War: Serving the National Interest*, ed. by Bernd Horn (Toronto: Dundurn Press Limited, 2006): 328-329.

[64] Andrew Godefroy, "The Intangible Defence: Canada's Militarization and Weaponization of Space," …, 336-337.

ballistic missiles from their homeland across extremely long distances. What this meant is that the US and the USSR, who had proven their capability to launch satellites, could also now aim ballistic missiles at each other. Those missiles could hold large payloads including nuclear warheads. Considering the reach of Russian ballistic missiles and that their trajectory would have them cross over Canadian territory to reach the US, it was natural that Canada would want to join force with its closest ally. The North American Aerospace Defense (NORAD) agreement was to solidify the Canada-US relationship and highlight joint roles in the deterrence against Soviet attacks. With the technology advances made on both sides of the Iron Curtain, the deterrence element would soon thereafter include ballistic missile and space systems.[65]

In the early 1980s, the NORAD role was expanded to include the detection, monitoring and tracking of space objects.[66] At the same time, US President Ronald Reagan launched the Space Defence Initiative (SDI). Although Canada declined to participate in this effort which was perceived as involving the deployment of weapons in space (something that the Canadian government was opposed to), it would nevertheless lead Canada to renew its space efforts.[67] A Senate Special Committee on National Defence recommended the establishment of a comprehensive defence space program to protect national security, which would involve the initial deployment of eight to 12 military spacecraft. The government did not approve the recommendations and aimed at a much reduced commitment instead focused on the ground segment. It would replace the aging Distant Early Warning (DEW) system supporting NORAD

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[65] Andrew Godefroy, “Is the Sky Falling? Canada’s Defence Space Programme at the Crossroads,” *Canadian Military Journal* (Summer 2000): 52.

[66] Andrew Godefroy, “The Intangible Defence: Canada’s Militarization and Weaponization of Space,”…, 339.

[67] Andrew Godefroy, “The Intangible Defence: Canada’s Militarization and Weaponization of Space,”…, 340.

with a new set of radar stations, the North Warning System (NWS) in the late 1980s.[68] The lack of political support and understanding for space activities in support of national sovereignty led the Americans to pursue space defence unilaterally as it became clear that Canada did not have the will nor the capacity to address space policy issues. It would not be until 1987 that the new defence white paper would recognize space as a strategic area of interest and that the first National Defence Space policy would be released.[69]

The end of the Cold War tempered the proposed efforts, but the strategic importance of space for national security remained, which was reinforced with the First Gulf War. During this conflict, the multiplier effect of space systems was clearly demonstrated and Canada witnessed it firsthand. The US-led coalition successfully employed space-based technologies such as satellite imagery, surveillance and reconnaissance, weather, communications and the newly deployed GPS constellation to rapidly bring the conflict to an end with minimal allied casualties.[70] Canada was unprepared to take advantage of space capabilities and instead relied almost entirely on American space systems for communications, navigation and intelligence gathering.[71] This war experience would bring the realization that access to space technologies would be essential to dominate in future conflicts. Furthermore, if Canada wanted to continue to participate and be in a position to leverage US systems, a more extensive defence space policy was required as well as a more comprehensive space program. These developments led to the 1992 National Defence

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[68] Andrew Godefroy, “The Intangible Defence: Canada’s Militarization and Weaponization of Space,” …, 341.

[69] Andrew Godefroy, “The Intangible Defence: Canada’s Militarization and Weaponization of Space,” …, 341-342; Department of National Defence, *National Defence Space Policy* (Ottawa: Canada Communications Group, 1987).

[70] Department of Defense, *Final Report to Congress: Conduct of the Persian Gulf War* (Washington, DC: April 1992), last updated 20 February 2014, http://www.dod.mil/pubs/foi/operation_and_plans/PersianGulfWar/404.pdf.

[71] Andrew Godefroy, “The Intangible Defence: Canada’s Militarization and Weaponization of Space,” …, 344-345.

Space Policy[72] and the establishment of the Director of Space Development (DSpaceD) in 1997 under the Deputy Chief of the Defence Staff (DCDS), a joint organization (as opposed to falling under the Air Force's purview). Despite challenging fiscal realities and defence reductions, the space policy was aimed at affirming Canada's commitment to be a partner in space activities, although actual level of efforts and expenditures would be limited. Securing continued close cooperation with the US was to be a focal point for DSpaceD to ensure the CAF's ability to leverage American capabilities while identifying burden sharing opportunities. [73]

The amount of staff and financial resources allocated to DSpaceD was not significant, but it allowed for the continuation of the space efforts and planning of future space engagements and activities both on the national level and with the US. In the late 2000s, DSpaceD would embark on a space awareness campaign within National Defence to better inform the senior leadership as to the criticality of space assets for military operations in order to garner internal support and ensure that everyone understood the role of DSpaceD and its mandate to provide space effects for soldiers, sailors and airmen/airwomen. It would also draft an updated National Defence Space Policy and Space Strategy, both key documents in detailing Canada's commitment to space security.[74]

In 2010, the DSpaceD was elevated and became the Director General Space Development (DGSpace), which included a small influx of personnel. The organization main focus is to

[72] Department of National Defence, *National Defence Space Policy* (Ottawa: Canada Communications Group, 1992).

[73] Andrew Godefroy, "The Intangible Defence: Canada's Militarization and Weaponization of Space," …, 345-347.

[74] Both the National Defence Space Policy and Strategy are still awaiting release in 2014.

"deliver agile, effective and affordable space support to the military".[75] Since the First Gulf War, space capabilities have continued to be more thoroughly integrated into all aspects of military operations. New space technologies have been developed furthering the space assets multiplier effect on the battlefield. Canada's resources remain limited and hence its dependency on American space systems endures. However, DGSpace is constantly looking at ways to increase Canada's burden sharing capabilities. For example Sapphire, a contributing sensor to the US Space Surveillance Network (SSN) was successfully launched in 2013 and now produces hundreds of observations per day.[76] Another one is the stand-up of the Canadian Space Operations Centre (CANSpOC) in 2012 as a node to the US Joint Space Operations Center (JSpOC) with an aim to keep a closer eye on Canadian satellites of interest, either government-owned, commercial or allied; and to provide a space common operating pictures to support CAF operations.[77]

In 2014, Canada's space defence collaboration with the US is significant. Key areas are highlighted below:

a. Satellite communications. The CAF has invested in the US Advanced Extremely High Frequency (AEHF) constellation of satellites in order to provide persistent and secure tactical communications to the warfighters in theatres of operations around the world. In June 2013, Canada became the first international partner to connect and use

[75] Brigadier General Rick Pitre, Director General Space Testimony in House of Commons, Standing Senate Committee on National Security and Defence, *Proceedings of the Standing Senate Committee on National Security and Defence*, no. 10, 19 Nov 2012, last accessed 5 June 2014, http://www.parl.gc.ca/content/sen/committee/411/SECD/pdf/10no..pdf..

[76] Paul Maskell, "Sapphire: Progress and Status," Presentation, 21 February 2014.

[77] Alicia Coulter, "Supporting Operations Through Space," *The Maple Leaf*, vol. 17, 5 May 2014, last accessed 5 June 2014, http://www.forces.gc.ca/en/news/article.page?doc=supporting-operations-through-space/ht6x4r56.

the first of six AEHF satellites. It is touted that "one satellite can provide greater total capacity than the entire legacy five-satellite Milstar constellation". [78] This key arrangement will allow Canada's military forces access to a portion of the satellites' capacity for survivable anti-jamming communications, while ensuring interoperability with Canada's closest allies.[79] Furthermore, another agreement was put in place using a similar model with the US WGS constellation of geostationary satellites. This capability provides a much larger capacity with high data rate transmission of voice and data information worldwide. The data is encrypted although not to the same level as what is offered by the AEHF constellation[80];

b. Position, Navigation and Timing (PNT). Under the NAVWAR umbrella, Canada, the US, the UK and Australia work at ensuring that their military forces continue to have guaranteed access to the GPS signals while denying their use by potential adversaries. The NAWWAR program looks at emerging threats, develop various equipment and techniques to allow operations in GPS-denied environment and to achieve PNT superiority[81];

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[78] "Canada Makes First Call on AEHF; First Partner Nation To Connect Terminals To Protected Communication Satellite," Lockheed Martin, 20 June 2013, last accessed 5 June 2014, http://www.lockheedmartin.ca/us/news/press-releases/2013/june/0620-ss-aehf.html.

[79] Brigadier General Rick Pitre, Director General Space Testimony in House of Commons, Standing Senate Committee on National Security and Defence, *Proceedings of the Standing Senate Committee on National Security and Defence…*

[80] Brigadier General Rick Pitre, Director General Space Testimony in House of Commons, Standing Senate Committee on National Security and Defence, *Proceedings of the Standing Senate Committee on National Security and Defence...*

[81] Brigadier General Rick Pitre, Director General Space Testimony in House of Commons, Standing Senate Committee on National Security and Defence, *Proceedings of the Standing Senate Committee on National Security and Defence…*

c. ISR. The space environment offers a unique vantage point for ISR sensors. By continually orbiting the Earth, a satellite can over time map and capture data from all around the globe (depending on the chosen orbit). The sensor can be focused on specific areas of interest and provide invaluable information on potential enemies and highlight changes in the landscape. ISR space-based sensors are used daily by the intelligence and defence planning community.[82] For example, Canada's space-based synthetic aperture radar capabilities have many applications including some particularly suited to defence operations such as wide area surveillance of the oceans and intelligence applications. By enabling Earth observation without the requirement for sun illumination as in the case for optical sensors, space-based radars can operate day and night and image areas of interest independent of weather. The Radarsat-2 satellite is an exquisite example of this capability.[83] Under the Polar Epsilon project, the CAF has built data receiving ground stations on both coasts in order to provide near-real-time information from Radarsat-2, which has dramatically increased maritime domain awareness.[84] Much of the fusioned Radarasat-2 data acquired by the CAF is shared with the US as their geography has very similar requirements.[85] The US possess a very extensive suite of space-based ISR sensors. Through various

[82] Space Foundation, *The Space Report 2012: The Authoritative Guide to Global Space Activity*, Arlington, 2012: , 25; David Emerson, Jacques Roy, Sandra Pupatello, and Jim Quick, *Reaching Higher: Canada's Interests and Future in Space* …, 20.

[83] Radarsat-2 is a radar satellite built, owned and operated by MacDonald Dettwiller and Associates. The Canadian Government partially funded the construction and launch of Radarsat-2 in exchange for data throughout the life of the mission, see Canadian Space Agency, "Radarsat-2," last modified 18 February 2011, http://www.asc-csa.gc.ca/eng/satellites/radarsat2/.

[84] Brigadier General Rick Pitre, Director General Space Testimony in House of Commons, Standing Senate Committee on National Security and Defence, *Proceedings of the Standing Senate Committee on National Security and Defence*…

[85] Due to commercial restrictions, the Radarsat-2 processed data cannot be shared as is with the US, but once it is fusioned with other information and built into an intelligence product, it can be provided.

intelligence arrangements, Canada benefits tremendously from the data obtained from those assets;

d. Search and Rescue (SAR). Canada and the US, along with France and Russia, are the founding nations of COSPAS-SARSAT, an organization supporting world-wide SAR through repeater payloads hosted on a variety of satellites. The organization now boasts 43 member states and is responsible for savings over 30,000 lives since its inception in 1982.[86] In Canada, the Department of National Defence (DND) has the mandate to lead Canadian efforts in this association. In the past, Canada has provided payloads for LEO platforms.[87] Current activities are focused on Medium Earth Orbit (MEO) SAR, specifically the inclusion of Canadian-built SAR payloads on the next generation of US GPS satellites slated to start launching in late 2015.[88]; and

e. Research and Development (R&D). Canada-US cooperation in space R&D is also noteworthy. Throughout the years, there have been many space related MOUs and PAs, such as the Trilateral Technology R&D Project (TTRDP) Small Satellite Military Utility Assessment PA. Many of these arrangements also include other close allies. With the proliferation of space technologies, the realities of financial constraints and the realization of the need for disaggregation (distribution of space

[86] "COMDEV MEOSAR Payload Clears Initial Design Review," *Space News*, vol. 25, No. 9, 3 March 2014: 14.

[87] Department of National Defence, "Reports on Plans and Priorities 2013-14," last accessed 5 June 2014, http://www.forces.gc.ca/en/about-reports-pubs-report-plan-priorities/2013-other-national-search-rescue-secretariat.page.

[88] "COMDEV MEOSAR Payload Clears Initial Design Review,"`…

capabilities across various platforms[89]) to protect space capabilities, international R&D cooperation is recognized and continues to expand; and

f. Space Surveillance Awareness (SSA). Canada has a long history in SSA. It began in the 1960s through NORAD, when Baker-Nunn cameras were installed on Canadian soil. Those ground-based optical sensors had for main function to collect, analyze and transmit satellite tracking data to NORAD. Later on as the list of on orbit satellites grew, they were also used to track Resident Space Objects (RSOs) for the US SSN. [90] Since then, the CAF have remained involved with SSA most recently with the launch of Sapphire, the first military operational satellite and the Near-Earth Object Surveillance Satellite/High Earth Orbit Surveillance System (NEOSSat/HEOSS) microsatellite, a SSA technology demonstrator. SSA will be discussed in more details in Chapter 5.

This list is not exhaustive, although it covers some of the most significant Canada-US collaborative efforts in the defence space area. With the CAF's space program limited resources, being able to effectively leverage American space systems is key to fulfilling Canada's space requirements in the delivery of the defence mandate.[91] It has been stated that the CAF "would never be able to make up from a loss of access to US (space) capabilities".[92] This chapter

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[89] Space disaggregation can be defined as: "The dispersion of space-based missions, functions or sensors across multiple systems spanning one or more orbital plane, platform, host or domain." See Department of Defense, *Resiliency and Disaggregated Space Architecture*, Air Force Space Command White Paper (Washington, DC: 2013), last accessed 5 June 2014, http://www.afspc.af.mil/shared/media/document/AFD-130821-034.pdf.

[90] Paul Maskell, and Lorne Oram, "Sapphire: Canada's Answer to Space-Based Surveillance of Orbital Objects," AMOS Technical Paper, 2008, last accessed 20 February 2014, http://www.amostech.com/TechnicalPapers/2008/SSA_and_SSA_Architecture/Maskell.pdf.

[91] Andrew Godefroy, "Is the Sky Falling? Canada's Defence Space Programme at the Crossroads,"…, 51.

[92] André Dupuis, personal conversation, 9 May 2014.

highlights the fact that space security in Canada is intimately intertwined to that of the US. Some political directions and policy differ. For example, Canada does not participate in ballistic missile defence although this decision is being reassessed.[93] The development of kinetic ASAT technologies is also something that is not being pursued by Canada, as this would be in contradiction of Ottawa's policy against the weaponization of space. Nevertheless, the close relationship between the two countries is such that most US space security concerns affect Canada to some extent, and vice versa. For example, threats to space systems that are worrisome to the US are also of interest to Canada. It is straight forward for threats coming from the space environment itself as those affect any satellites indiscriminately and they cannot be controlled. It is different in the case of hostile threats, where Canada's close relationship with the US brings an added level of complexity as will be discussed in the next chapter.

4. THREATS TO SPACE SYSTEMS

Nations are increasingly reliant on space capabilities to provide a wide range of data products and services that are used in daily life and critical to the functioning national economies. This dependence is also clearly apparent on the defence side. Space capabilities offer a tremendous advantage on the modern battlefield to those who control them. ISR assets, navigation, positioning and timing systems, and satellite communications are all critical to successful military operations for modern militaries. Furthermore, space systems offer a clear advantage in strategic decision-making for national and collective security by enabling a means to validate treaties and arm-control measures, as well as increasing the ability to respond to environmental

[93] House of Commons, Standing Senate Committee on National Security and Defence, *Canada and Ballistic Missile Defence: Responding to the Evolving Threat*, June 2014, last accessed 9 August 2014, http://www.parl.gc.ca/Content/SEN/Committee/412/secd/rep/rep10jun14-e.pdf.

disasters on the ground.[94] During the First Gulf War in Iraq, the application of space capabilities was integrated with the planning and execution of military operations for the first time.[95] The overwhelming advantage provided by space systems was realized not only by the coalition, but also by potential foes. Since then, the US and its allies have become increasingly reliant on space assets in the achievement of their mandates for national and international security. Unfortunately, this reliance on space capabilities has also brought important vulnerabilities that have not escaped would-be enemy's attention.[96] US Air Force General W.L. Shelton, Commander Air Force Space Command declared in 2014 that the continued mission success due to the successful integration of space capabilities into joint operations has "encouraged potential adversaries to further develop counter-space technologies and attempt to exploit our systems and information".[97] Hostile states and groups search for ways to impede US and allied access to space data and services in order to decrease their space advantage in an attempt to level the playing field.[98] Furthermore, many allied strategic space assets were conceived during the Cold War when the enemy was known and well-defined. They were most often large systems

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[94] C C. Robert. Kehler, "Implementing the National Security Space Strategy,"…; "Final Frontiers," Asia Pacific Defence Forum, 1 October 2013, last accessed 5 June 2014, http://apdforum.com/en_GB/article/rmiap/articles/print/features/2013/10/01/feature-pr-9.

[95] Department of Defense, *Final Report to Congress: Conduct of the Persian Gulf War…*

[96] Joshua Philipp, "US Alert to China Space Threat"…

[97] House of Representatives, *Hearing on National Defense Authorizations Act for Fiscal Year 2014 and Oversight of Previously Authorized Programs Before the Committee on Armed Services*, 113th Congress First Session, 25 April 2013, last accessed 5 June 2014, http://www.gpo.gov/fdsys/pkg/CHRG-113hhrg80769/html/CHRG-113hhrg80769.htm; Al-Qaeda is known to actively pursue ways to impede with the jamming and control of US unmanned aerial systems Those technologies could easily be applied against space systems. See Craig Whitlock, and Barton Gellman, "U.S. Document Detail Al-Qaeda's Effort to Fight Back Against Drones," *The Washington Post*, 3 September 2013., last accessed 9 August 2014, http://www.washingtonpost.com/world/national-security/us-documents-detail-al-qaedas-efforts-to-fight-back-against-drones/2013/09/03/b83e7654-11c0-11e3-b630-36617ca6640f_story.html; Iran demonstrated their jamming and hacking capabilities in 2011 when they captured a US RQ-170 unmanned aerial systems. See Peter B. De Selding, "Jamming No Mere Nuisance for Middle East Satellite Operators," *Space News*, 23 March 2012, last accessed 5 June 2014. http://www.spacenews.com/article/jamming-no-mere-nuisance-middle-east-satellite-operators.

[98] C. Robert. Kehler, "Implementing the National Security Space Strategy,"…

designed for a single-purpose and with minimal protection mechanisms.[99] Those space systems were defined based on the perceived threat at the time, as opposed to looking at the future security environment to determine which system would be best suited. The current security environment is very different and much more complex with a wide range of space actors whose intent is not always well characterized.[100] There is an increase in the number of countries and organizations developing military space capabilities, which has widen the range and probability of space systems threats.[101]

Threats to space systems can be broadly divided into three categories: natural, secondary impact and hostile threats. These will be defined in more details below:

a. Natural Threats. Satellites operate in a very harsh environment. They are exposed to the vacuum of space and extreme temperatures as they go in and out of the sun's view. There are also meteoroids of varying sizes. Satellites are travelling at a speed of several kilometers per second while orbiting the Earth[102], therefore even an impact with a tiny object could be catastrophic. Moreover, space weather phenomena can cause high energy particles to interfere with sensitive spacecraft systems such as solar panels and other electronics.[103] It is possible to harden

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[99] Rami R. Razook, and Frank C. Belz, "Meeting National Security Space Needs in the Contested Cyberspace Domain," *Aerospace Crosslink Magazine*, Spring 2012:1, last accessed 20 February 2014, http://www.aerospace.org/2013/07/26/meeting-national-security-space-needs-in-the-contested-cyberspace-domain/; James D. Rendleman, "Strategy for Space Assurance," in *Space Strategy in the 21st Century: Theory and Policy…*, 83.

[100] Department of National Defence, *The Future Security Environment 2013-2040*, Ottawa: 2013.

[101] Claire Jolly, "How Secure is Outer Space? Assessing the Threat to Space," last accessed 20 February 2014, http://ploughshares.ca/pl_publications/how-secure-is-outer-space-assessing-the-threat-to-space/.

[102] Satellites in LEO orbit on average at 7-8km/sec, while those in GEO have speeds in the order of 3km/sec.

[103] The NRCan website provides some more detailed explanation on space weather impact on spacecraft, see Natural Resources Canada, "Space Weather Effects on Satellites," last modified 21 November 2013, http://www.spaceweather.gc.ca/tech/se-sat-eng.php.

satellites to a certain extent, but it would be very difficult to make them able to withstand all space weather conditions;

b. Secondary Impact Threats. This type of threat is related to the hazards created by unintended interference. The frequency spectrum is one area where there are increasing risks for interference with an ever increasing number of active satellites in space. As spacecraft become closely integrated into progressively more complex networks and infrastructure, the risk of interference rises.[104] The GEO belt is a prime example. At GEO altitudes, spacecraft orbit the Earth every 24 hours, which means that a satellite in GEO remains over the same location over the Earth at any given time. Hence there are only a limited amount of locations where one can put a spacecraft. The geosynchronous orbit offers an excellent vantage point for communications satellite as they continually cover the same Earth footprint. As such, geosynchronous orbits are preferred and desired by many space-faring nations to provide national satellite communication coverage. Most GEO satellite operators are careful to move their spacecraft out of the GEO region once they have reached the end of their useful life to then launch another spacecraft to take its place. As more nations and commercial operators vie for the key GEO belt slots, it becomes overcrowded and there is greater potential for interference despite technology developments that allows for more effective use of the frequency spectrum, such as frequency hopping, digital signal processing

[104] Claire Jolly, "How Secure is Outer Space? Assessing the Threat to Space,"...

and frequency-agile transceivers.[105] In the past, each GEO satellite had a requirement for a minimum of three degree spacing between each spacecraft. This requirement was decreased to two degrees by the ITU to accommodate a larger amount of GEO space systems.[106] As the GEO spacecraft are located on average 42,000 km from the Earth surface, the power and frequency bandwidth required are significant. With less space between satellites, the risk of interference increases.

Another side effect of more closely spaced spacecraft is the increased potential for collisions. As the Earth is not a perfect sphere, there are variations in the satellite orbits. In other words, to remain at a precise location in the GEO belt, the orbits of the satellites have to regularly be slightly adjusted (through the use of propulsion mechanisms). They also have to sometimes be manoeuvred so as to avoid a potential collision with another spacecraft.[107] This matter is complicated by the fact that there are also many inactive satellites in the GEO belt. As mentioned earlier, current operators are careful at removing satellites before they become inactive, but that was not the case in the early days of space exploration. At the time, there were so few space actors that this issue was not recognized. These dead satellites migrate through the GEO belt and can require operators to move their satellite to avoid a collision. As the objects are so far away, they are also difficult to track from the ground, which compounds the threat of collisions.

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[105] Nancy Gallaguer, "International Cooperation and Space Governance Strategy," In *Space Strategy in the 21st Century: Theory and Policy*…, 55-56; Project Ploushares, *Space Security Index 2013*…, 11.
[106] Peter L. Hays, *Space and Security: A Reference Handbook* (Santa Barbara: ABC-CLIO, LLC, 2011), 89.
[107] Claire Jolly, "How Secure is Outer Space? Assessing the Threat to Space,"…

When discussing the risk of collisions in space, inactive satellites in the GEO belt are not the only concern. There are hundreds of defunct satellites orbiting the Earth. They are located across the range of available orbits and all present a potential threat. The collision between an active Iridium satellite and an inactive Russian Cosmos spacecraft in 2009 highlights this fact. Despite both being tracked by the US SSN, insufficient warning was provided and Iridium operators did not manoeuvre their satellite in time to avoid the collision.[108] Compounding the issue is that such an impact creates a cloud of debris, which then multiplies the collision risk. There are also many rocket bodies left-over and other objects, which are also travelling at several kilometers per second and could impact with another object. There is no doubt that the space environment where Earth orbiting satellites co-exist is getting increasingly congested. With over 20,000 man-made objects, 10 centimeters or more in size, being tracked and an estimated 300,000 larger than 1 centimeter and millions smaller pieces out there[109], the dangers of a non-intentional collision are real. Operational satellites often have to manoeuvre to avoid potential impact with inactive objects.[110] These objects not only threaten

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[108] Peter L. Hays, *Space and Security: A Reference* Handbook …, 89; Rathgeber, Wolfgang, Kai-Uwe Schrogl, and Ray A. Williamson, *The Fair and Responsible Use of Space: An International Perspective* (New York: Springer Wien, 2010): 73.

[109] Claire Jolly, "How Secure is Outer Space? Assessing the Threat to Space,"…

[110] For example, a French intelligence space asset had to perform a collision-avoidance manoeuvre on 23 April 2014, see Peter B. De Selding, "France Maneuvers Intel Satellite to Avoid Dead Weather Spacecraft," *Space News*, 23 April 2014: A3. Another example is with the recently launched European Sentinel-1A, which had to perform a collision avoidance manoeuvre less than 48 hours after separation from the rocket, which was the first time such a move needed to be executed during the Launch and Early Operations of a spacecraft, see Peter B. De Selding, "Close-Call: Europe's just Launched Sentinel-1A Dodges Dead Satellite," *Space News*, 10 April 2014, last accessed 5 June 2014, http://www.spacenews.com/article/civil-space/40164close-call-europe%E2%80%99s-just-launched-sentinel-1a-dodges-dead-satellite.

active satellites, but also the manned International Space Station (ISS). Several times a year, it has to be maneuvered to avoid debris objects.[111] This situation is only expected to worsen due to trends such as an increase in commercial space assets being launched and more countries developing national space capabilities. Moreover, there is a push for smaller satellites such as cubesats and nanosats, which are more difficult to detect and track.[112] There has also been a growth in technical developments in the fields of spacecraft propulsion, automation and rendezvous, which makes traditional tracking of satellites more complex as the objects no longer follow orbital mechanics models[113]; and

c. Hostile Threats. Finally, the last category refers to those threats purposefully intended to cause harm. This third type of threat has arisen due to man-made factors because of economic and military competition and the militarization of space.[114] Those threats can be further defined as reversible or non-reversible. A space system is comprised of one or more spacecraft, a ground segment for Telemetry, Tracking and Command (TT&C) of the satellite, and corresponding data links. Any of those elements is susceptible to disruption by hostile actors. Reversible threats are those that do not cause permanent damage. Electronic

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[111] Joshua Philipp, "US Alert to China Space Threat,"…; Alex Brown, "How to dodge a space bullet in Three (Not so Easy) Steps," *National Journal*, 3 (April 2014), last accessed 5 June 2014, http://www.nationaljournal.com/tech/how-to-dodge-a-space-bullet-in-three-not-so-easy-steps-20140403.

[112] There is no universally approved definition for cubesats and nanosats. They are generally considered to be 10cm3 and/or 10 grams or less.

[113] Peter L. Hays, *Space and Security: A Reference* Handbook…,77.

[114] The militarization of space refers to the use of space for military purposes. It is different than the weaponization of space, which refers to the deployment of weapons in space. Article IV of the OST prohibits the placement of nuclear weapons or weapons of mass destruction in outer space, see Patrick Gleeson, "Legal Aspects of the Use of Force in Space," (master thesis, McGill University, 2005), 87-95.

jamming is one example. It is most commonly done from the ground, but could also be performed by a neighbouring spacecraft. Jamming will prevent the effective transmission of a signal and hence could thwart key commands being sent to the satellite or prevent telemetry or data to be downloaded from the spacecraft. GPS jamming is a real threat in military operations made possible through the now wide availability of GPS jammers.[115] They can easily be built for less than $100 with commercial off the shelf parts and instructions from the internet.[116] There has been an increase in intentional jamming by criminal organizations and national entities which have disrupted GPS signals and satellite communications.[117] Laser blinding is another example. It is done from the ground through high-power lasers and is used to disrupt the operation of the spacecraft and its sensors.[118]

Non-reversible threats are those that will render a satellite permanently disabled. The most frequently cited example of this type of threat is a kinetic ASAT attack: a high-energy kinetic collision between two objects in space rendering both unusable. Orbital mechanics makes the trajectory of any satellite (without propulsion) highly predictable once some key parameters are known, most of

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[115] House of Representatives, *Hearing on National Defense Authorizations Act for Fiscal Year 2014 and Oversight of Previously Authorized Programs Before the Committee on Armed Services*, 113th Congress First Session, 25 April 2013, last accessed 5 June 2014, http://www.gpo.gov/fdsys/pkg/CHRG-113hhrg80769/html/CHRG-113hhrg80769.htm.

[116] Brigadier General Rick Pitre, Director General Space Testimony in House of Commons, Standing Senate Committee on National Security and Defence, *Proceedings of the Standing Senate Committee on National Security and Defence…*

[117] Project Ploushares, *Space Security Index 2013…*

[118] Todd Lowery, "Call it MIRACL," *The Bulletin of the Atomic Scientists* (January/February 1998): 5-6, last accessed 9 August 2014, https://www.armscontrol.org/act/1997_10/miracloct.

which are available or can be derived from open-source data.[119] This reality makes space systems inherently vulnerable. There are different types of kinetic ASAT systems, either direct ascent (where the ASAT is launched atop a rocket or plane and aimed directly at the target) or co-orbital (where the ASAT is launched and then manoeuvred close to the target). Kinetic ASAT systems create large amount of debris that can then impact any satellite indiscriminately.[120]

Aside from kinetic ASAT systems, there other ways to cause irreversible damage to a space system, such as high-power micro-wave weapons or lasers.[121] For example in the case of optical satellites, if one was to use an extremely high power laser, it could burn a charge-coupled device (CCD) and hence render the sensor useless. The coherent and highly directional beam of lasers can cause damage at distances of thousands of kilometres, although they require a very high level of precision.[122] Ground stations can also be the targets of attacks, which could cause irreparable damage to the mission if a TT&C segment was destroyed. As command antennas are usually fewer in number than payload data download antennas, if a spacecraft was operated through only one ground station, its

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[119] The JSPoC provides two-line element sets of most space objects tracked by the US SSN. They are available online, see Department of Defense, Space Track website, last updated 20 February 2014, https://www.space-track.org/auth/login.

[120] See Appendix 1 for a list of kinetic ASAT test; Nayef R.F Al-Rhodam, *Meta-Geopolitics of Outer Space: An Analysis of Space Power, Security and Governance…*, 78.

[121] Nayef R.F Al-Rhodam, *Meta-Geopolitics of Outer Space: An Analysis of Space Power, Security and Governance …*, 79.

[122] Nayef R.F Al-Rhodam, Meta-Geopolitics of Outer Space: An Analysis of Space Power, Security and Governance …, 80.

destruction would prevent any further communications with the spacecraft, hence rendering the space system useless. [123]

Finally, there is a growing awareness of the cyber threats to space systems. It has become increasingly important to be able to fuse information from various sources to provide intelligence analysis for the soldiers, sailors, airmen and airwomen, and there is a corresponding requirement for increasing networking capability to allow for timely communications across the globe. This enabling connectivity applies to space ISR and satellite communications assets and it has also injected vulnerabilities.[124] As with ground-based networks, a satellite computer system could be infiltrated and interfered with. Cyber-attacks could be aimed at the physical, hardware or software layer of a space system. For example, in the case of software infiltration, the impact could be disastrous as software changes are not always easy to do depending on the platform and how it was designed. Once a bug is injected in a space system, it might not be able to recover. There have already been reported US cyber-attacks on cryptographic certificates used for the command of satellites as well as on the German space research centre. [125]

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[123] Toffler Associates, Protecting our Space Capabilities: Securing the Future…, 3.

[124] Brigadier General Rick Pitre, Director General Space Testimony in House of Commons, Standing Senate Committee on National Security and Defence, Proceedings of the Standing Senate Committee on National Security and Defence…

[125] Rami R. Razook, and Frank C. Belz, "Meeting National Security Space Needs in the Contested Cyberspace Domain,"…, 2; "German space research centre under espionage attack," Space Daily, 3 April 2014, last accessed 20 February 2014, http://www.spacedaily.com/reports/German_space_research_centre_under_espionage_attack_report_999.html.

For the purpose of this research paper, hostile threats are of utmost interest. With the increasing number of space actors whose intent is not always known, it is expected that counterspace capabilities of potential adversaries will proliferate and become more robust in a reduced timeline.[126] Countries such as China are already developing space system negating capabilities such as laser blinding systems and kinetic space weapons.[127]

Hostile intent with respect to space systems is often related to asymmetric warfare. As mentioned earlier, Western armed forces are highly dependent on space systems in the conduct of their operations. As the majority of operations are performed in a joint fashion, the Western militaries always have a net military advantage over weaker opponents. This superiority combined with the inherent vulnerabilities of space technologies could lead potential adversaries to favour asymmetric threats in space in order to even the balance of power. In other words, foes that cannot compete with conventional warfare means could use asymmetric acts, such as the malevolent use of spacecraft and sabotage, on allied space systems as a way to gain an advantage.[128] It has even been argued that future conflicts will inevitably include asymmetric means directed at space technologies.[129] Three actors will be addressed: Russia, China and non-state actors.

RUSSIA

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[126] House of Representatives, *Hearing on National Defense Authorizations Act for Fiscal Year 2014 and Oversight of Previously Authorized Programs Before the Committee on Armed Services…*

[127] Claire Jolly, "How Secure is Outer Space? Assessing the Threat to Space,"…

[128] Nayef R.F Al-Rhodam, Meta-Geopolitics of Outer Space: An Analysis of Space Power, Security and Governance …, 89.

[129] Nayef R.F Al-Rhodam, Meta-Geopolitics of Outer Space: An Analysis of Space Power, Security and Governance …90.

During the Cold War, Washington and Moscow put in place many arrangements and measures to prevent catastrophic conflict escalation. The nuclear threats were real on both sides of the Atlantic, but there was a tacit understanding that neither would impede each other's space systems.[130] Although no longer an open enemy of the US and its allies, Russia remains a nation of interest. The unfavorable state of its economy and declining technology advance momentum have not discontinued their investment in military space capabilities. For example, the Russians are providing the only available spacecraft able to bring astronauts to the ISS. They are also developing the Angara next generation of launch vehicles to replace their current aging launchers.[131] They retain the second largest fleet of military space systems after the US.[132] Furthermore, despite opposing co-orbital kinetic ASAT systems through the PPWT proposal and advertised position against the placing of weapons in space, Russia's actions suggest that they continue the development of active airborne kinetic ASAT capabilities with the Sokol Eshelon and Kontakt programs.[133]

The recent situation in Crimea and Ukraine has shown that in many aspects, Russia is not aligned with Western policies. The tensions in early 2014 have strained Moscow's relations with the Western world. Most notably Russia has been excluded from the G8 (a select group of leading industrialized nations that they were part of since 1997), which has now become the G7

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[130] J James D. Rendleman, "Strategy for Space Assurance," in *Space Strategy in the 21st Century: Theory and Policy…*, 83-84.

[131] Project Ploushares, *Space Security Index 2013…*, 14.

[132] Project Ploushares, *Space Security Index 2013…*, 16; The International Institute for Strategic Studies, *The Military Balance 2013…,226.*

[133] Jana Honkova, "The Russian Federation's Approach to Military Space and Its Military Space Capabilities" (Arlington: The Marshall Institute, November 2013): 34-40, last accessed 9 August 2014, http://marshall.org/wp-content/uploads/2013/11/Russian-Space-Nov-13.pdf.

following Russia's violation of Ukraine's sovereignty. [134] For a while, it seemed space cooperation would continue unhampered, especially with regards to manned space flight with the launch of the ISS crew (Expedition 40) on 28 May 2014. [135] However, the Russian Deputy Prime Minister announced in May 2014 that in response to sanctions imposed on Russia they would no longer support the ISS after 2020, would prohibit the use of Russian engines for the launch of US national security satellites (the Russian built RD-180 engines are used on the American Atlas 5 rockets) and would decommission ten GPS ground stations located in Russia.[136] Moreover, the Canadian government technology demonstrator Maritime Monitoring and Messaging Microsatellite (M3MSat) was prohibited from being shipped and launched from Russia in June 2014 as planned.[137] The decision came from the GoC and it highlights the decreasing level of comfort between Canada and Russia. It is not to say that Moscow would be willing to take hostile action, but it is something to consider in evaluating threats to space systems Canada relies on.

CHINA

China continues to expand its space program and has made important strides in achieving space power status. With the launch of two 'taikonauts' on their indigenous rocket in 2003, China became the third country after the Russians and Americans to launch their own astronauts in

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[134] Department of Foreign Affairs, "Trade and Development. "G7/G8"," last accessed 5 June 2014, http://www.international.gc.ca/g8/index.aspx.

[135] National Aeronautics and Space Administration, "International Space Station: Expedition 40," last accessed 5 June 2014, http://www.nasa.gov/mission_pages/station/expeditions/expedition40/.

[136] Warren Fernster, "U.S. Sanctions, Russian Response Fraying Once-Strong Space Ties," *Space News*, vol. 25, No. 20, 19 May 2014:1,16.

[137] David Pugliese, "Russian Sanctions Have Killed Canadian Satellite Launch," *Ottawa Citizen*, 23 April 2014., last accessed 5 June 2014, http://www.ottawacitizen.com/technology/Russian+sanctions+have+killed+Canadian+satellite+launch/9772896/story.html.

orbit.[138] It has also been the third nation to land a spacecraft on the moon in December 2013.[139] Beijing space exploration exploits are paralleled by a tremendous development in military space capabilities. China possesses its own national PNT system in the Beidou constellation (the Chinese equivalent of the American GPS), numerous imaging and other intelligence assets, weather satellites, and a series of satellite telecommunications systems. Anti-satellite capability development is also a key aspect of their space program.[140] The Chinese have demonstrated their kinetic ASAT technology when they destroyed one of their defunct satellites in 2007. This event will be remembered as one that showcased Chinese progress but more for the amount of resulting debris, the largest debris cloud ever created.[141] Previous kinetic ASAT tests done by the US and the Russians had involved destroying their own satellites that was orbiting at very low altitude. Hence the debris created would burn up in the atmosphere in a matter of months, therefore limiting the risk that a piece would unintentionally collide with another spacecraft.[142] In the Chinese test, the object destroyed was at a much higher altitude. It resulted in an impressive cloud of debris that will remain in orbit for centuries. Moreover, these debris objects are in a very similar orbit to Canada's Radarsat satellites. Radarsat-1 was turned off last year after over 15 years in orbit delivering an incredible amount of data[143], but Radarsat-2 is still active. Although it has not entered in collision with any pieces of debris yet, Radarsat-2 has been moved

[138] "China Sends First Man Into Space," *BBC News*, 15 October 2003, last accessed 20 February 2014, http://news.bbc.co.uk/onthisday/hi/dates/stories/october/15/newsid_3699000/3699842.stm

[139] http://www.space.com/23968-china-moon-rover-historic-lunar-landing.html.

[140] Joshua Philipp, "US Alert to China Space Threat"...

[141] Joshua Philipp, "US Alert to China Space Threat"…; Lauchie Scott, "Orbital Debris Implications Resulting from the ASAT Intercept of 11 January 2007," Technical Report, Defence R&D Canada – Ottawa, December 2007, 2.

[142] This is due to the atmospheric drag lowering the debris objects' speed hence their altitude. The drag increases at lower altitudes.

[143] Canadian Space Agency, "Radarsat-1: Seventeen Years of Technological Success," last modified 9 May 2013, http://www.asc-csa.gc.ca/eng/media/news_releases/2013/0509.asp.

a few times in order to avoid a potential impact.[144] While the Chinese most likely did not intend to threaten Canadian satellites with their ASAT test, a direct result of this experiment is that while Radarsat-2 remains active (which could be for many more years if one is to look at the Radarsat-1 legacy), there will always be a threat of collision. Space surveillance technology is such that objects as small as 10 centimeters can be detected, but there are also thousands of smaller pieces that are not tracked, each of which could cause a catastrophic impact. Compounding this issue is that the government is planning a follow-on to Radarsat-2, referred to as the Radarsat Constellation Mission (RCM), which will consist of three satellites that are to be launched in a similar orbit.

Although China has proven its kinetic ASAT capability, it is unclear whether they would be willing to use it against Canadian or allied assets. The subsequent ASAT tests conducted after 2007 used a much lower orbiting target, which minimized the debris created, hinting that they were becoming a more responsible space nation.[145] However, their responsible behaviour in space should not be assumed.[146] Chinese officials have not been forthcoming with respect to their kinetic ASAT testing. For example, in May 2014 a Dong Ning-2 ASAT missile was launched, although it was reported to be for a scientific mission under the national Chinese

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[144] Lauchie Scott, "Orbital Debris Implications Resulting from the ASAT Intercept of 11 January 2007,"…, 27.

[145] Weeden, Brian, "Through a Glass, Darkly: Chinese, American, and Russian Anti-satellite Testing in Space," Secure World Foundation, 17 March 2014:1, last accessed 20 February 2014, http://swfound.org/media/167224/Through_a_Glass_Darkly_March2014.pdf.

[146] Michael Krepon, "Promoting National and Economic Security Interests in Space,"…

Academy of Sciences.[147] Another anti-satellite test took place in July 2014, this one claimed to be a land-based missile interceptor.[148]

China's intentions are of concern. The links between Beijing military and civil space programs are blurry and although there is a lot of publicity about their space program being for science and exploration, it is believed to be directly supporting defence activities.[149] With their kinetic ASAT testing and other space endeavours, it would seem that China is prepared to explore the full spectrum of space capabilities to "expand the limits of conventional war to the space domain".[150] It has been reported by Dr. Ashley Tellis, expert on South Asia affairs, that "Chinese military planners are deeply focused on neutralizing US space capabilities because of their belief that such neutralization is essential to whittle down dominance on which the US military depends for its success".[151] Beijing has also recently increased activities related to the development and deployment of over 50 satellites in the next few years for surveillance and Earth monitoring, which could also serve intelligence purposes.[152] Furthermore, the Chinese are pursuing the development of the Long March-5, their next generation of indigenous launchers, aiming at landing a taikonaut on the moon.[153] Other countries are also concerned about China. For example

[147] Joshua Philipp, "US Alert to China Space Threat"...

[148] Mike Gruss, "U.S. State Department Says China Conducted an Anti-satellite Test," *Space News*, vol. 25, No. 31, 4 August 2014: 10.

[149] Project Ploushares, *Space Security Index 2013…*, 16.

[150] James D. Rendleman, "Strategy for Space Assurance," in *Space Strategy in the 21st Century: Theory and Policy…*, 84.

[151] Ashley J. Tellis, "China's Counterspace Programs - Only More Bad News," in Department of Defense, *Joint Hearing on the People's Republic of China's Counterpace Program and the Implications for U.S. National Security*, House Armed Services Subcommittee on Strategic Forces, 28 Jan 2014, last accessed 9 June 2014, http://docs.house.gov/meetings/AS/AS29/20140128/101680/HHRG-113-AS29-Wstate-TellisA-20140128.pdf.

[152] "China eyes 'global monitoring network," *Space Daily*, 3 April 2014, last accessed 20 February 2014, http://www.spacedaily.com/reports/China_eyes_global_monitoring_network_of_surveillance_satellites_999.html.

[153] Project Ploushares, *Space Security Index 2013…*, 14.

India and Israel are building a missile defence system and pursuing nuclear weapon development in order to protect against nuclear strikes that could come from China.[154]

Looking at its space history, capabilities and intent, China is believed to be the nation most likely to pose a threat of space systems disruption.[155] Despite China's involvement in the UN CD, based on the Chinese efforts deployed in the space area in the last decade, it is reasonable to assume that within the next twenty years they will have fully operational national satellite communications, space-based navigation and ISR assets that will most likely be integrated with their other military capabilities. It is expected that Chinese reliance on space systems will hence increase similarly to what has been seen in other space powers.[156] This dependence is hopefully going to increase China's conscience with regards to instability intent. Therefore, Canada should continue monitoring Chinese space development and activities to ensure that none become a threat to Canadian space systems of interest.

NON-STATE ACTORS

As space technologies become more common and accessible, the number of nations and commercial entities owning spacecraft systems increases. As mentioned above, there are now over 170 states which use space assets for national and commercial benefits.[157] Non-state actors can also exploit space technologies. For example, many universities develop small but capable

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[154] "Israel, India Agree on Missile Defence System Against China," *World Tribune* (2 April 2014), last accessed 9 August 2014, http://www.worldtribune.com/2014/04/02/israel-india-agree-on-missile-defense-system-against-china-pakistan-nuclear-strikes/.

[155] Micah Zenko, "Dangerous Space Incidents," *Council on Foreign Relations, Contingency Planning Memorandum 21* (April 2014), last accessed 9 August 2014, http://www.cfr.org/space/dangerous-space-incidents/p32790?sp_mid=45655631&sp_rid=dGdyaWV2ZUBuYXRpb25hbGpvdXJuYWwuY29tS0.

[156] James D. Rendleman, "Strategy for Space Assurance," in *Space Strategy in the 21st Century: Theory and Policy…*, 83.

[157] House of Representatives, *Hearing on National Defense Authorizations Act for Fiscal Year 2014 and Oversight of Previously Authorized Programs Before the Committee on Armed Services…*

space systems (such as Canada's University of Toronto Space Flight Laboratory), and rebellious groups use satellite communications to broadcast their message.[158] Hezbollah even owns a satellite television channel with an annual budget in millions of dollars and which is used to broadcast anti-American propaganda.[159] It is also now possible for hostile non-state actors to acquire systems, which could be used to disrupt space assets.[160] Developing elaborate anti-satellite technologies remain complex and expansive, but jammers and cyber warfare equipment are commonly available. There exist some groups such as the Taliban which would have the means to develop more advanced anti-satellite systems that could potentially pose a threat to space capabilities, although this is not likely in the near future as there are other much less expansive ways to cause disruption.[161]

The future security environment points to asymmetric capabilities that could be developed by potential adversaries, which will make the space common even more complex. This chapter has shown the range of threats faced by space systems. Many of the threats presented could be directed at Canadian space systems or those Canada depends upon. It is important to highlight that Ottawa needs to be concerned not only with assets owned by the Canadian government, but national commercial systems such as communications satellites by Telesat and the Radarsat systems, as well as allied system such as the US AEHF, WGS and GPS constellations, which Canada relies on. These space capabilities are critical not only for military operations and national security, but to ensure the Canadian way of life. It could be argued that, with Canada's

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[158] Jeffrey Lewis, "The Role of Non-State Actors in Outer Space Activities, in United Nations Institute for Disarmement Research, *Building the Architecture for Sustainable Space Security - Conference Report 30-31 March 2006* (Vienna, 2006): 32.

[159] Matthew Levitt, *Hezbollah: The Global Footprint of Lebanon's Party of God* (London: C. Hurst & Co, 2013): 332.

[160] laire Jolly, "How Secure is Outer Space? Assessing the Threat to Space,"…

[161]Eric Schmitt, "Many Sources Feed Taliban's War Chest," *The New York Times*, 18 October 2009, last accessed 9 August 2014, http://www.nytimes.com/2009/10/19/world/asia/19taliban.html.

stance against space weaponization and limited government-owned assets and space budget, why should Canada be worry about hostile threats to space systems? Why would anybody want to inflict damage or interfere with Canadian space capabilities or those it relies on? Three reasons could be possible. The first relates to Canada's close relationships with the US. As mentioned in Chapter 3, Canada's space security is intimately linked to that of its Southern neighbour. The Americans possess the largest fleet of space assets, which Canada is largely dependent upon. It is recognized that Washington has more potential adversaries than Ottawa. Considering those facts, there is a larger chance that US systems could be attacked. Depending on the damage caused, the impact to Canada could be significant. For example, interference or loss of one of the WGS satellites during a military operation with Canadian soldiers on the ground could prevent the transmission of key information or commands that could result in a loss of life. Significant degradation of the GPS signals or malicious infiltration of time delay would be disastrous for pilots and precision-guided weapons. It would also cause havoc for Canadian banks and hydro-electric power grids, which are both dependent on the precise timing provided by GPS, resulting in the loss of power for countless households and a significant loss in revenues.

Secondly, Canada usually participates in military operations with the US and other NATO nations. As part of a coalition, participating countries therefore become the 'enemy' from an adversary point of view and Canadian assets could become a target as much as any other allied space systems. As discussed in Chapter 4, space systems are inherently vulnerable, which makes them prime targets for asymmetric attacks. As it has been experienced in recent conflicts such as in Afghanistan and Libya, opponents that have been weaker from a conventional stand-point have reached for asymmetric warfare tactics. There have been reports of jamming and laser blinding although no significant damage ensued.[162] Ram Jakhu, associate professor for the Institute of Air and Space Law at McGill University has reported that there has been a dramatic increase in intentional jamming in recent years.[163] He cited the deliberate interference during political unrest in the Middle East (Arab Spring) as an example, aimed at preventing the dissemination of information.[164] Iran and Syria have been the source of much of the recent intentional jamming.[165]

Civilian infrastructure and systems can also be targets. For example, Eutelsat noted that jamming incidents with their space systems doubled between 2010 and 2011; and tripled between 2011 and 2012. They were able to attribute the interference to Iran, Syria or Bahrain in most of the cases.[166] Future security trends and the increased proliferation of accessible counter-space technologies indicate that disruption of space systems will continue. It can be expected that the level of potential damage could increase as jamming incidents and capabilities proliferate and missile system and directed energy weapon development continues.[167]

Finally, the Canadian government is becoming more involved in space. Aside from launching two spacecraft in 2013 (Sapphire and NEOSSat) and another one ready to go (M3MSat), it is planning two new constellations in the next few years: one is the RCM and the other the Polar

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[162] Micah Zenko, "Dangerous Space Incidents,"…

[163] Mike Gruss, "Military Satellite Communications | Panel Ties U.S. Troop Rotations to Satellite Interference Spikes." *Space News*, 24 June 2013, last accessed: 5 June 2014, http://www.spacenews.com/article/military-space/35948military-satellite-communications-panel-ties-us-troop-rotations-to.

[164] Peter B. De Selding, "Jamming No Mere Nuisance for Middle East Satellite Operators,"…

[165] Mike Gruss, "Military Satellite Communications | Panel Ties U.S. Troop Rotations to Satellite Interference Spikes."…

[166] Clare Hill, "Satellite and Internet Jamming Worsening," *Commonwealth Broadcasting Association*, 28 November 2012, last accessed 9 August 2014, http://www.cba.org.uk/latest/satellite-and-internet-jamming-worsening/.

[167] Project Ploushares, *Space Security Index 2013…*, 19.

Weather and Communications (PCW) constellation. Those will add five satellites considered key for national sovereignty to the government-owned space inventory. Combined with the changing geopolitical environment and rise in the number of space actors, it will become imperative for Ottawa to ensure spacecraft system access and protection as they could also become targets.

The potential hostile threats to Canada's space systems and those it relies on need to be addressed to continue enjoying the data and services space capabilities bring. Canada needs to start looking more carefully at protecting the space asset systems it depends on, while developing mechanisms to counter space interference by other states/organizations. As it has been demonstrated, kinetic ASAT systems are not the only hostile threat to satellites, there exists a wide range of options to hamper Canada's ability to exploit space assets. Although there is a

need to develop the capabilities to contend with the threats to the space systems Canada relies on, an effective space deterrence posture is also required. Such a stance would allow Canada to increase the chances that a conflict could be averted early on and encourage space stability by preventing the escalation of hostilities in space. It would also align with its diplomatic mid-power legacy and national policy supporting the peaceful use of space.[168] Space deterrence and means to strengthen it were discussed in Chapter 2. It is now time to examine a critical enabler of space deterrence: SSA, and demonstrate how it could positively contribute to Canada's space deterrence posture.

[168] Department of National Defence, *National Defence Space Policy* (Ottawa: Canada Communications Group,1998).

5. SSA

SSA is an area that has received increased international attention in the last decade due to the space environment becoming increasingly congested, contested and competitive. SSA comprises all of the information that is required to provide an alertness of the space environment. It is concerned with space weather, natural phenomena that can disrupt satellites (as defined in Chapter 3), as well as the tracking and identification of orbiting space objects. A decline in debris production was observed in the 1990s and early 2000s mostly due to debris mitigation measures adopted by many countries, but this trend came to end after the Chinese ASAT test in 2007 and the unintentional collision between an Iridium and defunct Cosmos satellite in 2009, which both created large clouds of debris that will remain in orbit for decades to come.[169]

[169] Project Ploushares, *Space Security Index 2013…*, 10.

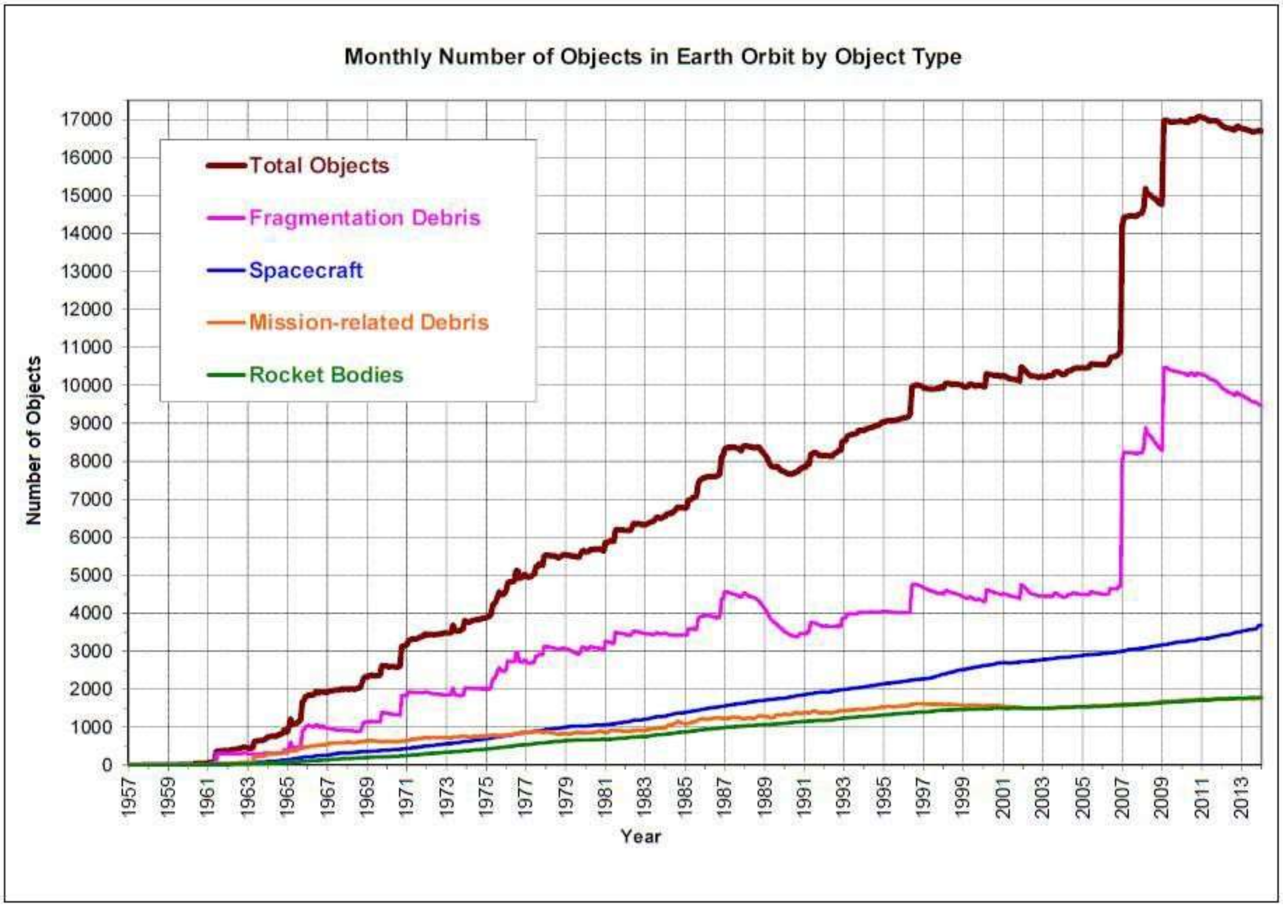

Figure 1. Growth in the On-orbit Population of RSOs by Category

Source: National Aeronautics and Space Administration, *Orbital Debris Quarterly News*, vol. 18, no. 1 (January 2014), last accessed 5 June 2014, http://orbitaldebris.jsc.nasa.gov/newsletter/pdfs/ODQNv18i1.pdf.

The US has been leading the SSA efforts for many years through the USSTRACOM JSpOC, which is responsible for the SSN.[170] The main purpose of the SSN is to detect and track RSOs orbiting the Earth, including the launch of new spacecraft. The tracked RSOs are comprised of active and inactive satellites, as well as thousands of pieces of debris. The JSpOC routinely track

[170] Peter L. Hays, *Space and Security: A Reference Handbook*…, 89.

on average 23,000 RSOs.[171] Figure 2 shows their current distribution. The cluster of objects close to the Earth's surface represents the LEO satellites. Further out, forming a ring, are the GEO spacecraft. Each takes 24 hours to rotate around the Earth and thus always oversee the same region.

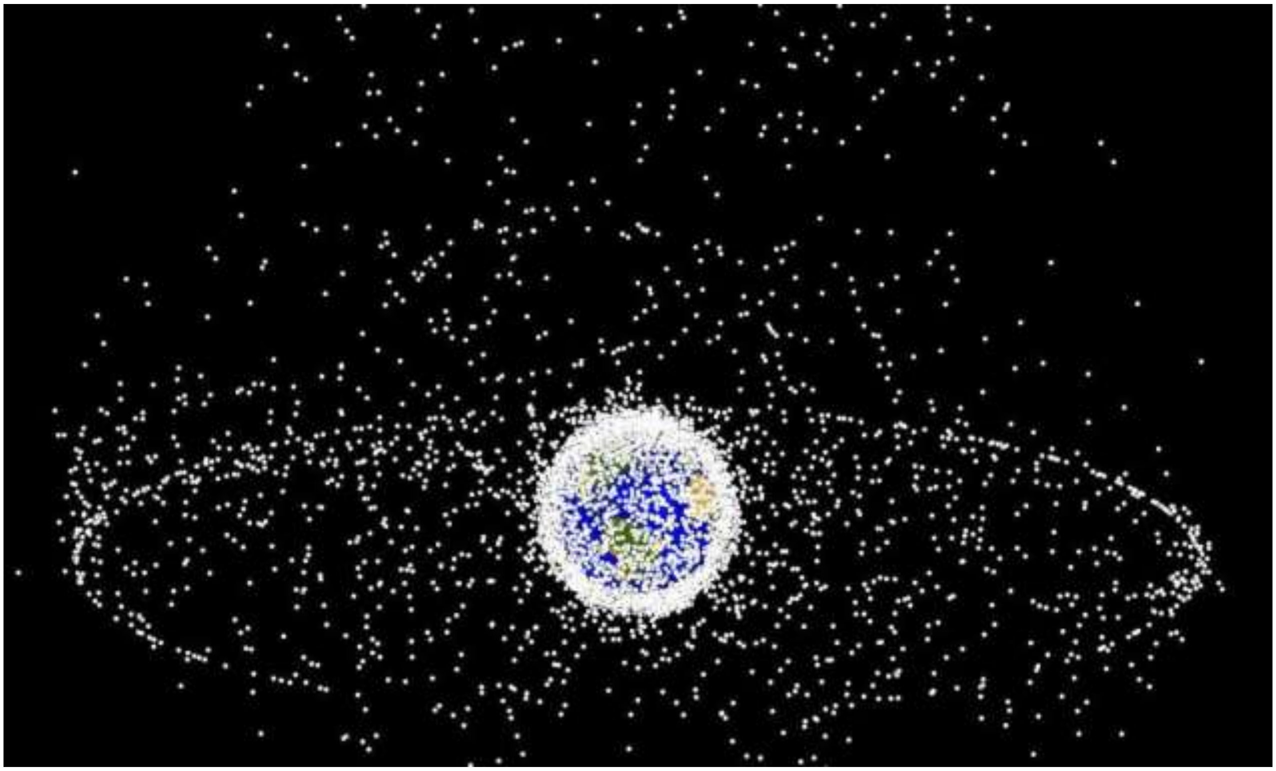

Figure 2. RSO Distribution

Source: National Aeronautics and Space Administration, "Orbital Debris Graphics – GEO Images," last accessed 9 August 2014, http://orbitaldebris.jsc.nasa.gov/photogallery/beehives.html.

The SSN is comprised of a range of optical and radar sensors distributed across the globe and tasked by the JSpOC. Most of the systems are ground-based, but there are also a few space-based sensors, such as Canada's National Defence's Sapphire satellite. The location of current sensors

[171] House of Representatives, *Hearing on National Defense Authorizations Act for Fiscal Year 2014 and Oversight of Previously Authorized Programs Before the Committee on Armed Services…*

is displayed at Figure 3. Current sensor technology enables the SSN sensors to reliably track objects down to 10 centimeters in size in LEO (and 1 meter in GEO), but models points at a population of over 500,000 objects under that size that are currently not tracked and seemingly invisible to the SSN and spacecraft operators.[172] These smaller objects could catastrophically damage satellites and manned spacecraft at any time.

Figure 3. US SSN Dedicated Sensors

Source: Department of Defense, "USSTRACOM Space Control and Space Surveillance," last updated January 2014, http://www.stratcom.mil/factsheets/11/Space_Control_and_Space_Surveillance/.

Without its own space doctrine, Canada turns to its closest ally to frame the SSA rationale.[173] US joint doctrine publications define SSA as: "the requisite current and predictive knowledge of the space environment and the operational environment upon which space operations depend." It encompasses four functional capabilities, namely Characterization, Detection / tracking /

[172] House of Representatives, *Hearing on National Defense Authorizations Act for Fiscal Year 2014 and Oversight of Previously Authorized Programs Before the Committee on Armed Services…*

[173] André Dupuis, personal conversation, 9 May 2014.

identification, Threat warning and assessment, and Data integration and exploitation.[174] As Figure 4 demonstrates, SSA is very broad and is critical to successful space operations. It is truly the central piece that "enables all operational activities".[175] The US SSN is but one piece of the SSA puzzle as it is focused mainly on the detection, tracking, identification and cataloging of RSOs. The new JSpoOC Mission System being deployed will provide enhanced computing capability in order to provide better detection and characterization of orbital and hostile threats, but other capabilities are required to complement the SSN in order to provide complete SSA.[176] Although the US has tried to do it all by themselves, the complex nature of SSA has proven a tough challenge. Those efforts have been further complicated by the harsh fiscal realities, which have affected space military spending.[177] Sharing SSA knowledge is mutually beneficial and helps all spacecraft operators in that it can increase spaceflight safety while minimize the risk of on-orbit collision by providing threat warning. The importance of SSA in providing a greater understanding of the RSOs population, space environment and potential threats for the safety of spaceflight is recognized.[178] The US National Space Security Strategy clearly highlights a need for greater cooperation in the SSA realm to fill the current gaps and add capabilities.[179] These developments have led the Americans to take steps to share SSA information with commercial entities, as well as seek international SSA partnerships. For example, Canada signed a bilateral

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[174] Department of Defense, *Joint Publication 3-14*, *Space Operations*, last updated 29 May 2013, http://www.dtic.mil/doctrine/new_pubs/jp3_14.pdf.

[175] C. Robert. Kehler, "Implementing the National Security Space Strategy,"…

[176] House of Representatives, *Hearing on National Defense Authorizations Act for Fiscal Year 2014 and Oversight of Previously Authorized Programs Before the Committee on Armed Services...*

[177] House of Representatives, *Hearing on National Defense Authorizations Act for Fiscal Year 2014 and Oversight of Previously Authorized Programs Before the Committee on Armed Services…*.

[178] Rathgeber, Wolfgang, Kai-Uwe Schrogl, and Ray A. Williamson, *The Fair and Responsible Use of Space: An International Perspective*…, 78.

[179] Department of Defense and Office of the Director of National Intelligence, *National Security Space Strategy…*

SSA MOU in 2012.[180] Australia, Italy and Japan are other nations with which the US now possess data sharing arrangements with and more are in the works.[181] Moreover, to complement the JSpOC , the US is pursuing efforts to expand this SSA centre of excellence into a Coalition Space Operations Center (CSpOC) with its closest allies.[182] The Canadian contribution will be discussed in the next chapter.

The US is not the only country working on providing better SSA. Europe is also putting in place its own SSA system. This effort is led by the European Space Agency, a civilian organization.[183] Russia also possesses a significant network of sensors for SSA mainly focused on LEO objects, although they do not share the data. In addition, China and India possess extensive telemetry, tracking and control infrastructure.[184] Canadian involvement with SSA was briefly mentioned in Chapter 3. It is now time to look at Canada's past, current and future participation and contribution to SSA.

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[180] Department of National Defence, "Space Situational Awareness and the Sapphire Satellite," last modified 30 January 2014. http://www.forces.gc.ca/en/news/article.page?doc=space-situational-awareness-and-the-sapphire-satellite/hr0e3oag.

[181] Warren Fernster, "U.S., Canadian Governments Sign SSA Data-Sharing Accord," *Space News*, vol. 25, No. 2, 13 January 2014: 3.

[182] C. Robert. Kehler, "Implementing the National Security Space Strategy,"…

[183] Rathgeber, Wolfgang, Kai-Uwe Schrogl, and Ray A. Williamson, *The Fair and Responsible Use of Space: An International Perspective*…, 83.

[184] Project Ploushares, *Space Security Index 2013*…, 12.

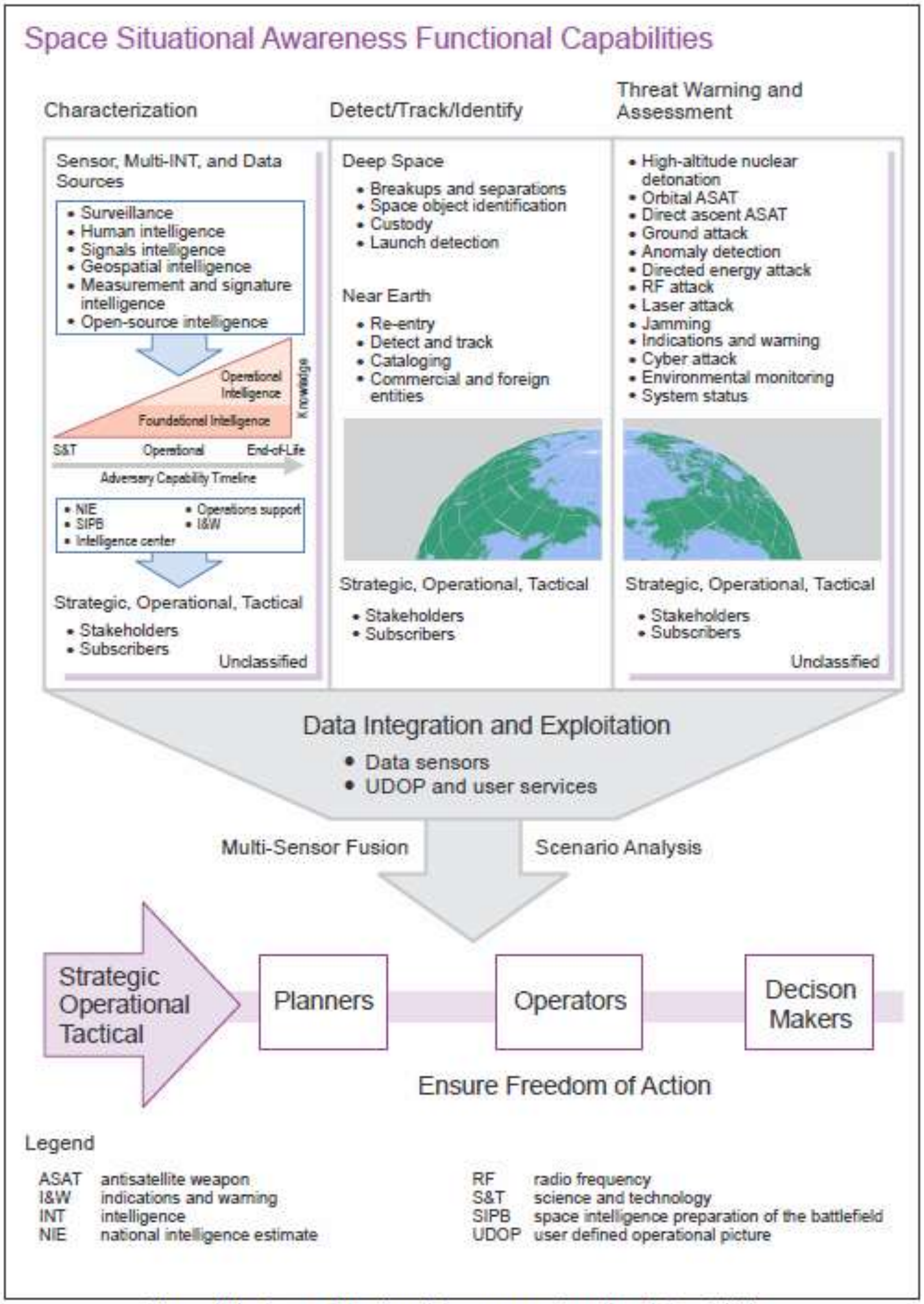

Figure II-1. Space Situational Awareness Functional Capabilities

Figure 4. Description of SSA Functional Capabilities

Source: Department of Defense, *Joint Publication 3-14, Space Operations*, last updated 29 May 2013, http://www.dtic.mil/doctrine/new_pubs/jp3_14.pdf.

6. SSA AND THE CAF

Canada has a long history in SSA. It started under NORAD with the installation of a Baker-Nunn camera at RCAF Station Cold Lake, Alberta in 1961 and another one a few years later in St. Margaret, New Brunswick. In the 1990's, the Baker-Nunn cameras were discontinued due to obsolescence and Canada looked at ways to continue contributing to the SSN.[185] In parallel with the National Defence ground-based SSA efforts, the Department of External Affairs (a precursor to the Department of Foreign Affairs, Trade and Development) sponsored a study in the mid-1980s for a space-based remote sensing sensor for arms treaty verification from space, referred to as PAXSAT, although this initiative never resulted in a satellite development program.[186] In 1996, the Americans launched an experimental space-based optical sensor to track RSOs, the Midcourse Space Experiment (MSX) with for payload the Space-Based Visible (SBV) sensor.[187] Due to SBV's mission effectiveness, it was later operationalized and integrated as a contributor sensor to the US SSN until 2008.[188] With SBV, Canada saw a potential niche that would continue its involvement in SSN. National Defence henceforth put in place the Surveillance of Space Project. The option analysis identified a small optical satellite as the best way forward, which would be named Sapphire. It would be complementing the American Space Based Space

[185] Paul Maskell, and Lorne Oram, "Sapphire: Canada's Answer to Space-Based Surveillance of Orbital Objects,"…

[186] Walter Dorn, "Paxsat: A Canadian Initiative in Arms Control." Peace Magazine (October-November 1987): 17, last accessed 9 August 2014, http://peacemagazine.org/archive/v03n5p17.htm; Department of Foreign Affairs, Trade and Development, "PAXSAT 'A' Space Remote Sensing: Space-to-Space," DFATD Library, vol. 1, January 1985, last accessed 7 August 2014, http://dfait-aeci.canadiana.ca/view/ooe.b4108942E_001#ooe.b4108942E_001/16?r=0&s=1&_suid=14076122145750046560933163765195.

[187] Grant H. Stokes, et al., "The Space-Based Visible Program," *MIT Lincoln Laboratory Journal*, vol. 11, no. 2 (1998), last accessed 5 June 2014, https://www.ll.mit.edu/publications/journal/pdf/vol11_no2/11_2space.pdf.

[188] Herbert J. Kramer, "Space-Based Surveillance System," *Earth Observation Portal*, last accessed 20 February 2014. https://directory.eoportal.org/web/eoportal/satellite-missions/s/sbss.

Surveillance (SBSS) satellite, which was launched in 2010.[189] Sapphire was delivered to orbit in February 2013 and is the first Canadian operational military satellite. The spacecraft has now completed commissioning and is producing hundreds of daily observations that are fed directly to the SSN as a contributing sensor to the network.[190]

Another Canadian spacecraft was launched at the same time as Sapphire, this one a R&D microsatellite. This satellite is a joint technology demonstrator between National Defence and the CSA with two primary missions. The first is a CSA mission to track asteroids referred to as Near Earth Object Surveillance Satellite (NEOSSat). The second is led by the Defence Research and Development Centre-Ottawa (DRDC-O) and has for main objective to track man-made objects in space to support SSA, called High Earth Orbit Space Surveillance (HEOSS).[191] The latter mission is very similar to that of Sapphire, the difference being that it is aiming at demonstrating the utility of microsatellites to perform space-based surveillance of the space environment. It also seeks to further explore what can be done for SSA with a small space-based optical sensor and how it can help filling some of the current gaps.

In parallel with the development of space-based SSA systems, Canada signed a bilateral SSA MOU with the US, which was followed in 2012 by a SSA Data Sharing Agreement, tightening the bilateral cooperation. This accord allows for streamlined access to critical information pertaining to the planning of satellite manoeuvres, collision prevention and support in case of

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[189] Department of Defense, "Space-Based- Space Surveillance," last updated 26 March 2013, http://www.afspc.af.mil/library/factsheets/factsheet.asp?id=20523.

[190] Paul Maskell, "Sapphire: Progress and Status," ...

[191] Lauchie Scott, Martin Lévesque, and Stefan Thorsteinson, "Toward Microsatellite Based Space Situational Awareness," AMOS technical Paper, 2013, last accessed 20 February 2014, http://www.amostech.com/TechnicalPapers/2013/International_Programs/SCOTT.pdf.

anomalies.[192] In order to better exploit this SSA information and provide more timely space effects to soldiers, sailors and airmen/airwomen, the CAF stood up the CANSpOC as part of the CSpOC in 2012.[193] In addition to providing burden-sharing with allies, one of the main goal of the CANSpOC is to access all relevant SSA information focusing especially on Canadian space assets of interests, including commercial space systems the CAF are dependent upon.[194] The CANSpOC will "deliver the critical space enablers to our forces and our strategic partners within government in close cooperation with our allies around the world".[195] It is expected to reach full operational capability in 2015.

In addition to ongoing activities with Sapphire, NEOSSat/HEOSS and the CANSpOC, significant efforts are being made to look at follow-on capabilities. For example, the Surveillance of Space 2 project has recently completed its option analysis to continue the Canadian SSA contribution after Sapphire. Although Sapphire was only launched in 2013 and has a design life of five years, the traditional length of space project development means that the follow-on endeavour needs to be started now to ensure that the new capability will be in place before Sapphire is retired. After a thorough examination, the recommended option for the project is for a mix of ground and space-based systems.[196] The Sapphire follow-on is not only important for Canada to continue its SSA contribution, but also due to the SSN gap in space-based sensors.

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[192] Warren Fernster, "U.S., Canadian Governments Sign SSA Data-Sharing Accord,"…

[193] Brigadier General Rick Pitre, Director General Space Testimony in House of Commons, Standing Senate Committee on National Security and Defence, *Proceedings of the Standing Senate Committee on National Security and Defence…*

[194] Department of National Defence, "Draft Concept of Operations – Canadian Space Operations Center," Ottawa, 2014; Brigadier General Rick Pitre, Director General Space Testimony in House of Commons, Standing Senate Committee on National Security and Defence, *Proceedings of the Standing Senate Committee on National Security and Defence…*

[195] Brigadier General Rick Pitre, Director General Space Testimony in House of Commons, Standing Senate Committee on National Security and Defence, *Proceedings of the Standing Senate Committee on National Security and Defence…*

[196] Paul Maskell, "Option Analysis for the Surveillance of Space 2 Project," Department of National Defence, 16 April 2014.

Currently, the US SBSS is also on orbit but its follow-on will not be launched until 2021 mainly due to an austere fiscal environment which delayed the program.[197] This will leave a four-year potential gap in American systems; hence the Canadian SSA contribution becomes even more critical.[198]

Moreover, the US has identified a requirement for further capabilities to be developed in the SSA area. For example, it is necessary to improve the tracking of RSOs, especially those smaller in size that are currently not detectable, provide better characterization and object identification, and increase computer analysis power. In addition, it is necessary to enhance the capability to detect anomalies and differentiate between non-intentional and hostile behaviour in space.[199] By continuing investing in SSA capabilities, Canada can once again help fill the gap.

On the R&D side, there are also plans to continue SSA research. The NEOSSat/HEOSS science is expected to start in the later part of 2014. The microsatellite will be a key asset to observe RSO's of interest, detect anomalies and look at SSA aspects operational space-based sensors do not have time to focus on. Furthermore, a new ambitious SSA focused research project was recently approved. It will further SSA expertise in RSO detection and identification, trend analysis, assessment of emerging technologies and explore ways of improving SSA capabilities to fill identified gaps.[200]

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[197] House of Representatives, *Hearing on National Defense Authorizations Act for Fiscal Year 2014 and Oversight of Previously Authorized Programs Before the Committee on Armed Services...*

[198] Gruss, Mike. "With SBSS Follow-on in Limbo, U.S. Space Surveillance Gap Looms." *Space News*, vol. 25, No. 8, 24 February 2014:1.

[199] Rathgeber, Wolfgang, Kai-Uwe Schrogl, and Ray A. Williamson, *The Fair and Responsible Use of Space: An International Perspective…*, 76.

[200] Department of National Defence, "Charter for Space Situational Awareness and Emerging Technologies Project," Defence R&D Canada – Ottawa, April 2014.

7. HOW CAN SSA SUPPORT SPACE DETERRENCE?

It is now appropriate to present the arguments for how SSA can support space deterrence. As discussed in Chapter 2, two main conditions are required for successful deterrence. The first is related to having the capability to inflict significant damage as a result of a space attack and the second refers to the intent to actually use that capability in response. There is currently no 'defence or deterrence strategy to prevent an attack on space assets'[201] However there is a need to influence the cost benefits analysis as to no longer favor potential enemies.

SSA in itself does not fulfill any of the two conditions for space deterrence. However because deterrence is dependent on knowing the state of play, SSA becomes a critical piece of any space deterrence posture.[202] It is the foremost enabler.[203] US General John F. Sheldon stated: "effective deterrence is strengthened by the fact that SSA could potentially indicate the nature and origin of any attempted attack on a satellite".[204] Ultimately, SSA helps to maintain the peaceful use of space by providing better awareness of what is 'out there' and enabling attribution.[205]

As discussed at Chapter 5, SSA allows for the identification and tracking of RSOs in order to provide warning of potential collisions in orbit. It also provides the means to differentiate between natural and hostile actions in space through the identification of anomalies and provision of warning and information on various satellites which can then by processed to allow

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[201] Toffler Associates, *Protecting our Space Capabilities: Securing the Future…*, 4.

[202] Michael Krepon, "Responding to China's Counter-space Capabilities,"…

[203] Rathgeber, Wolfgang, Kai-Uwe Schrogl, and Ray A. Williamson, *The Fair and Responsible Use of Space: An International Perspective…*, 76.

[204] John B. Sheldon, "Space Power and Deterrence: Are we serious?" (Washington, DC: The Marshall Institute, November 2008), last accessed 20 February 2014, http://marshall.org/wp-content/uploads/2013/08/616.pdf.

[205] Rathgeber, Wolfgang, Kai-Uwe Schrogl, and Ray A. Williamson, *The Fair and Responsible Use of Space: An International Perspective…*, 77.

for proper response or to minimize damage caused to space assets.[206] SSA has inherent deterrence importance, because if hostile agents recognize that their disruption could be quickly detected, correctly attributed and advertised, they would have to consider the potential long-term impact of angering their target owner. If that would be the US or a close ally, the punishments could be significant.[207]

Moreover, SSA contributes to space stability and security by "preventing misunderstandings and false accusations of hostile actions". If the SSA data is shared, it furthers its contribution to space sustainability as it becomes a type of CBM by increasing transparency.[208] If it is not possible to attribute disruption accurately, then potential adversaries could see that as an opportunity to hamper allied space systems access without the risk of retaliation. Therefore reliable SSA and better understanding the space environment becomes essential to allied forces for space deterrence.[209]

8. CANADA, SPACE DETERRENCE AND SSA

The previous chapters have explored space governance, the space deterrence concept, Canada's close relationship with the US, the space threats and SSA. Some key points have been ascertained:

a. Space governance is incomplete. Aside from the outdated 1967 OST, there are no internationally legally binding agreements addressing space weaponization and ensuring space security and sustainability. Although there have been attempts at

[206] Michael Krepon, "Responding to China's Counter-space Capabilities,"…
[207] RAND Corporation, *Deterrence and First-Strike Stability in Space: A Preliminary Assessment…*, 48.
[208] Project Ploushares, *Space Security Index 2013…*, 12.
[209] Rathgeber, Wolfgang, Kai-Uwe Schrogl, and Ray A. Williamson, *The Fair and Responsible Use of Space: An International Perspective…*, 100.

developing a new treaty, there does not seem to be much appetite by the preeminent space nations to adopt another legally binding agreement. Instead the trend is for CBMs and codes of conduct, which are less restrictive but still allow for some internationally acceptable space guidelines to be established. There is also no international body that could enforce these 'rules of the road', although the UN Security Council could fill this role as this would contribute to maintaining peace and security.[210] With more and more countries possessing space assets and an even higher number increasingly dependent on space data and services, the lack of space governance and international space authority is concerning;

b. Space deterrence is complex. It does not follow the traditional nuclear deterrence model on several aspects, most notably because there are more than two primary actors and potential hostile threats to space systems are more widespread than during the Cold War. Furthermore, ASAT technology is not mandatory for space deterrence. There are many other ways to establish a space deterrence posture such as through disaggregation and diplomatic means. Canada is already involved in most of these approaches and it is assumed that it holds an informal space deterrence posture;

c. The unique CA-US relationship in the space arena dates back to the beginning of the space age. It has endured despite the sometimes wavering Canadian political

[210] United Nations General Assembly, *United Nations Charter*, last accessed 20 February 2014, http://www.un.org/en/documents/charter/chapter5.shtml.

commitment. Due to the net security and military advantage provided by space assets, space data and services have been increasingly integrated into military operations. Therefore both countries are heavily reliant on space systems. Canada is highly dependent on the Americans for the provision of satellite communications, PNT, imagery and weather to name a few. Although new Canadian government systems are being planned and developed, the fiscal and political reality is such that it is extremely doubtful that Ottawa could become self-sufficient in the next decade. Hence any threat to American systems that Canada is dependent upon should be of great interest;

d. Threats to space systems exist. There are an increasing number of nations already in possession or developing technologies that could cause both reversible and irreversible damage to space systems. There are also a growing number of non-state actors with the capabilities to interfere or cause severe damage to space assets and infrastructure. Satellite systems are inherently vulnerable despite efforts to increase their protection; therefore they make excellent targets for asymmetric attacks;

e. SSA has been a strategic space area for Canada since the 1960s. Through relatively small contributions, the CAF have obtained a tremendous amount of data in return. Through the Surveillance of Space 2 project and the defence R&D SSA program, efforts are continuing. SSA has secured Canada’s position as a space faring nation and a responsible space user. Canada has developed a niche capability that is contributing to making the space common safer and more stable. Gaps in SSA capabilities have been recognized and with its SSA history, Canada is extremely well positioned to continue making a significant contribution in this area, both through capital investments and R&D activities; and

f. SSA is a key element for space deterrence as it provides the ability to differentiate between natural or unintended interference with space assets of interest and malicious intent. It also allows for attribution, which is critical in identifying the perpetrator and hence determining the proper response.

It is now time to return to the original question this research paper is attempting to answer: Will continued involvement in SSA by the CAF positively contribute to Canada's space deterrence posture? Three arguments points to the affirmative. The first is related to the close link between effective space deterrence and SSA, the second is focused on the CA-US relationship, and the last argument is linked to the extension of the Canadian SSA involvement. Each will be further discussed below.

SSA is a key enabler of any space deterrence stance. It is absolutely essential to be able to correctly attribute any disruption to space systems. Without the capacity to identify the perpetrator, it would not be possible to devise the right response. Without knowing the state or organization behind the hostile act, it would be unfeasible to identify with certainty its intent and hence extremely challenging to tailor a space deterrence strategy. Canada's direct involvement with SSA through the US SSN and recent CANSpoC establishment increase Canadian SSA knowledge and the ability to differentiate between unintentional and hostile interference.

Furthermore, the important research efforts in this area enable better detection and identification techniques to be developed and used operationally. Consequently, because SSA is such a critical element for successful space deterrence, the CAF' participation in SSA strengthens the Canadian space deterrence posture.

Secondly, Canada has been linked to the US in SSA since the beginning of space exploitation. The US possess the most extensive SSA network and expertise in the world. Other countries are building and expanding their capabilities, but none can rival the Americans yet. Canada enjoys a privileged relationship with the US in SSA and is currently the only foreign country with a national asset as a contributing sensor to the SSN. Moreover, Sapphire is only one of two active space-based systems devoted to the SSA (the other being the US SBSS), which offers a key vantage point to observe RSOs above LEO. Through this direct contribution and unique partnership, Canada benefits from access to key SSA data obtained by other sensors and can leverage American analysis expertise. Therefore Canada not only gets data from its own assets, but also has access to the considerable American SSA apparatus. If a potential adversary were to attempt attacking Canadian space systems or those it is dependent upon, both Canadian and American SSA could be used to identify the offender, which would greatly reduce the chance that it would remain anonymous. Although Ottawa's stance on space deterrence is not clearly stated as of yet, it is understood that any serious interference or attack on space systems used for national security would not go unanswered. The government's refusal to launch a Canadian defence technology demonstrator from Russia in response to Moscow's behaviour in Crimea and Ukraine highlights the fact that the space systems are key national assets even if their capability is limited as in the case of research spacecraft. If a hostile agent knew there would be high chances that it would be identified, its willingness to attack would be greatly diminished if it was not in a position to sustain significant retaliation. Hence Canadian SSA participation with the US supports a stronger space deterrence posture.

Finally, the third argument is related to the level of Canadian SSA involvement. The last ten years have seen a significant increase in SSA spending, most notably through the establishment of a ground-based optical research sensor as well as a space asset (Sapphire). This has led to closer ties with the US, but also greatly contributed to the development of indigenous space expertise. A case in point, Defence Research and Development Canada (DRDC) is now recognized as a SSA centre of excellence by the GoC and its allies, and has launched a SSA technology demonstrator (NEOSSat) in 2013, it also hosts world-renowned SSA experts. Furthermore the recent stand-up of the CANSpOC has brought a more operational element to SSA in Canada, as it is collocated with the Canadian Joint Operations Command (CJOC) Centre. In addition, the CSA is also aspiring to play a greater role in SSA, which will broaden the Canadian SSA expertise outside the defence area. Through the ongoing activities related to the Surveillance of Space 2 project, which aims at continuing the Canadian contribution to SSA and the SSA R&D program, Canada demonstrates that it is considering SSA as a strategic capacity and it is committed to allocating resources from the limited pool available to this space area. Continued National Defence investment and work devoted to SSA in filling the gaps will further increase the capabilities and expertise. It is therefore reasonable to expect that with continued investment, better SSA will be available to Canada, either through more sensitive or better positioned sensors or through improved analytical capabilities. It will then become even easier to differentiate between malevolent interference with Canadian satellites of interest or natural event effects. Even if it is assumed that hostile actors will also continue to develop ASAT technologies and other asymmetric means to disrupt space systems, better SSA will always be valuable and allow the friendly force to maintain an advantage. If the work continues on both sides at the same rate, this superiority should prevail. Continuing to invest in SSA and ensuring that involvement is advertised will positively contribute to Canada’s space deterrence position. Exploring collaborative opportunities in SSA with Russia and China could also reinforce space deterrence.

If Canada was to stop its involvement with SSA and focus on other areas of its space program, what impact would it have? First, SSA is increasingly important to better understand the environment as more and more spacecraft are being launched. The international community recognizes the requirement for better SSA and more countries are developing systems for that purpose. If Ottawa, after years of involvement in the area, decided to no longer invest in SSA, it is expected that it would reflect poorly on the country as this is a domain clearly identified as critical for space flight safety. Secondly, Canada’s SSA participation is closely linked to that of the US. It is doubtful whether the Americans would still share all of their data without any contribution in return. As the need for SSA data would still remain as long as Canada owns spacecraft and is dependent on space assets (which will continue for the foreseeable future), Canada would most likely be relegated at getting only a scrubbed down version of the data, similar to those provided to commercial entities and other minor space player. Canada would lose its privileged status at least on the SSA realm and could miss key information that could impact the safety of its assets. Third, there would be a loss of national expertise in the area that has taken years to acquire and therefore Canada could no longer be considered as a leader in SSA research. Finally, losing expertise and access to critical SSA information would also negatively impact the Canadian space deterrence position. Without key SSA data and analysis, attribution would be much more difficult in case of a space system disruption. It would deprive Canada of this key space deterrence enabler. Now, what is the probability that Canada would stop investing in SSA? It is estimated very low. As Colonel André Dupuis, Acting DGSpace stated in 2014: "SSA will not only remain a strategic area for Canada, but it will grow".[211] The ongoing and future planned activities indicate that SSA involvement will in fact continue.

CONCLUSION

The security environment is complex and is expected to remain so.[212] There are now tens of space actors and with space technologies becoming increasingly easier to acquire, it is anticipated that this number will continue to grow. Most actors are using space capabilities to better lives and to improve the management of resources, but the intent of some other nations and organizations are not as clear and could even be hostile to Canada and its allies. Satellite systems are inherently fragile. This vulnerability combined with a significant dependence on space systems and the proliferation of space agents, some who could have unfriendly intentions, creates an unhealthy situation that if realized could negatively impact the Canadian way of life. In other words, this combination yields a fertile ground for hostile entities to consider space systems as targets for disruption. Depending on the level of interference or damage created, it could have dire consequences.

Ideally, any conflict involving space systems should be avoided. Deterring anyone from disrupting Canada's space systems or those it is dependent upon should be a national strategic

[211] André Dupuis, personal conversation, 9 May 2014.
[212] Department of National Defence, *The Future Security Environment 2013-2040…*

objective. Although all the right elements for effective space deterrence are present in Canadian space related efforts, a formal space deterrence stance has not been developed and advertised by the government. Red lines detailing which level of disruption could be tolerated would need to be established as well. SSA allows for the monitoring of the space environment and enables the attribution of space events affecting space systems. Hence Canadian active involvement in SSA allows for the detection and characterization of hostile offenders and for the determination of when a red line threshold has been crossed. SSA therefore becomes a key element for space deterrence.

It has been argued that Canada holds an informal space deterrence posture. This position is reinforced through participation in SSA activities, both nationally and with the US. It was further established that continued investments in the SSA realm will positively contribute to Canada's space deterrence posture. Although this paper has mostly explored SSA's role in space deterrence, Chapter 2 has highlighted that there are several ways to reinforce space deterrence which do not require a kinetic ASAT program or other active space countermeasures. It would be in Ottawa's best interest to more seriously consider adopting a formal space deterrence stance now that the threat to Canadian space assets, although real, can be considered to be low. As a Schriever Wargame clearly demonstrated, once hostilities appear imminent it is extremely difficult to plan and establish an effective space deterrence position.[213]

Recent discussions on space security at high levels of the Canadian government are a good sign that there is more political interest to address this issue. Canada has already made great strides towards space deterrence; a consolidated position considering its closest allies would better

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[213] Susan Helms, "Schriever Wargame 2010: Thoughts on Deterrence in the Non-Kinetic Domain,"…,

prepare the nation if the threat level was to increase while strengthening Canada's role in international space security.

APPENDIX 1 – LIST OF KINETIC ASAT TESTS

The following tables present successful kinetic ASAT tests. [214]

US KINETIC ASAT TESTS

Program/Operation	Date of Test (dd/mm/yyyy)	Target Object	Interceptor Object	Interceptor type	Trackable Debris Created
ASM-135	13/09/1985	Solwind	ASM-135	Direct ascent	285
Burnt Frost	21/02/2008	USA 193	LEAP*	Direct ascent	174

*LEAP: Lightweight Exo-Atmospheric Projectile, launched from a Standard Missile 3 (SM-3).

SOVIET KINETIC ASAT TESTS

Program/Operation	Date of Test (dd/mm/yyyy)	Target Object	Interceptor Object	Intercept or type	Trackable Debris Created
Istrebitel Sputnikov (IS)	20/10/1968	Cosmos 248	Cosmos 249, Cosmos 252 (IS)	Co-orbital	251
Istrebitel Sputnikov (IS)	23/10/1970	Cosmos 273	Cosmos 374, Cosmos 375 (IS)	Co-orbital	145
Istrebitel Sputnikov (IS)	25/02/1971	Cosmos 394	Cosmos 397 (IS)	Co-orbital	116
Istrebitel Sputnikov (IS)	03/12/1971	Cosmos 459	Cosmos 462 (IS)	Co-orbital	27
Istrebitel Sputnikov (IS)	17/12/1976	Cosmos 880	Cosmos 886 (IS)	Co-orbital	67
Istrebitel Sputnikov (IS)	19/05/1978	Cosmos 970	Cosmos 1009 (IS-M)	Co-orbital	5
Istrebitel Sputnikov (IS)	18/04/1980	Cosmos 1171	Cosmos 1174 (IS-M*)	Co-orbital	41
Istrebitel Sputnikov (IS)	18/06/1982	Cosmos 1375	Cosmos 1379 (IS-M)	Co-orbital	3

*Upgraded version of the IS interceptor.

CHINESE KINETIC ASAT TESTS

Program/Operation	Date of Test (dd/mm/yyyy)	Target Object	Interceptor Object	Intercept or type	Trackable Debris Created
Unknown	11/01/2007	Fengyun 1C	SC-19	Direct ascent	3280

[214] Weeden, Brian, "Through a Glass, Darkly: Chinese, American, and Russian Anti-satellite Testing in Space." Secure World Foundation, 17 March 2014. Last accessed 20 February 2014. http://swfound.org/media/167224/Through_a_Glass_Darkly_March2014.pdf.

BIBILOGRAPHY

Al-Rhodam, Nayef R.F. *Meta-Geopolitics of Outer Space: An Analysis of Space Power, Security and Governance*. Hampshire: Palgrave MacMillan, 2012.

Baines, Philip. "The Potential for Outer Space CBMs." In United Nations Institute for Disarmement Research. *Building the Architecture for Sustainable Space Security - Conference Report 30-31 March 2006*. Vienna, 2006: 16-17.

Brown, Alex. "How to dodge a space bullet in Three (Not so Easy) Steps." *National Journal*, 3 (April 2014). Last accessed 5 June 2014. http://www.nationaljournal.com/tech/how-to-dodge-a-space-bullet-in-three-not-so-easy-steps-20140403.

Canada. Canadian Space Agency. "Radarsat-1: Seventeen Years of Technological Success." Last modified 9 May 2013. http://www.asc-csa.gc.ca/eng/media/news_releases/2013/0509.asp.

Canada. Canadian Space Agency. "Radarsat-2." Last modified 18 February 2011. http://www.asc-csa.gc.ca/eng/satellites/radarsat2/.

Canada. Department of Foreign Affairs. "Trade and Development. "G7/G8"." Last accessed 5 June 2014. http://www.international.gc.ca/g8/index.aspx.

Canada. Department of Foreign Affairs, Trade and Development. "PAXSAT 'A' Space Remote Sensing: Space-to-Space." DFATD Library, vol. 1, January 1985. Last accessed 7 August 2014. http://dfait-aeci.canadiana.ca/view/ooe.b4108942E_001#ooe.b4108942E_001/16?r=0&s=1&_suid=1 4076122145750046560933163765195.

Canada. Department of National Defence. “Charter for Space Situational Awareness and Emerging Technologies Project.” Defence R&D Canada – Ottawa, April 2014.

Canada. Department of National Defence. “Draft Concept of Operations – Canadian Space Operations Center.” Ottawa, 2014.

Canada. Department of National Defence. “Reports on Plans and Priorities 2013-14.” Last accessed 5 June 2014. http://www.forces.gc.ca/en/about-reports-pubs-report-plan-priorities/2013-other-national-search-rescue-secretariat.page.

Canada. Department of National Defence. “Space Situational Awareness and the Sapphire Satellite.” Last modified 30 January 2014. http://www.forces.gc.ca/en/news/article.page?doc=space-situational-awareness-and-the-sapphire-satellite/hr0e3oag.

Canada. Department of National Defence. *National Defence Space Policy.* Ottawa: Canada Communications Group, 1987.

Canada. Department of National Defence. *National Defence Space Policy.* Ottawa: Canada Communications Group, 1992.

Canada. Department of National Defence. *National Defence Space Policy.* Ottawa: Canada Communications Group,1998.

Canada. Department of National Defence. *The Future Security Environment 2013-2040*. Ottawa: 2013.

Canada. House of Commons. Standing Senate Committee on National Security and Defence. *Canada and Ballistic Missile Defence: Responding to the Evolving Threat*. June 2014. Last accessed 9 August 2014. http://www.parl.gc.ca/Content/SEN/Committee/412/secd/rep/rep10jun14-e.pdf.

Canada. House of Commons. Standing Senate Committee on National Security and Defence. *Proceedings of the Standing Senate Committee on National Security and Defence*, no. 10, 19 Nov 2012. Last accessed 5 June 2014. http://www.parl.gc.ca/content/sen/committee/411/SECD/pdf/10no..pdf.

"Canada Makes First Call on AEHF; First Partner Nation To Connect Terminals To Protected Communication Satellite." Lockheed Martin, 20 June 2013. Last accessed 5 June 2014. http://www.lockheedmartin.ca/us/news/press-releases/2013/june/0620-ss-aehf.html.

Canada. Natural Resources Canada. "Space Weather Effects on Satellites." Last modified 21 November 2013. http://www.spaceweather.gc.ca/tech/se-sat-eng.php.

Chambers, William A. "Foreword." In Lowther, Adam. *Deterrence: Rising Powers, Rogue regimes, and Terrorism in the Twenty-First Century*. New-York: Palgrave MacMillan, 2012.

"China eyes 'global monitoring network." *Space Daily*, 3 April 2014. Last accessed 20 February 2014.

http://www.spacedaily.com/reports/China_eyes_global_monitoring_network_of_surveillance_satellites_999.html.

"China Sends First Man Into Space." *BBC News*, 15 October 2003. Last accessed 20 February 2014. http://news.bbc.co.uk/onthisday/hi/dates/stories/october/15/newsid_3699000/3699842.stm.

"COMDEV MEOSAR Payload Clears Initial Design Review." *Space News*, vol. 25, No. 9, 3 March 2014: 14.

Coulter, Alicia. "Supporting Operations Through Space." *The Maple Leaf*, vol. 17, 5 May 2014. Last accessed 5 June 2014. http://www.forces.gc.ca/en/news/article.page?doc=supporting-operations-through-space/ht6x4r56.

David, Leonard. "China Lands on the Moon: Historic Robotic Lunar Landing Includes 1st Chinese Rover." *Space.com*, 14 December 2013. Last accessed 5 June 2014. http://www.space.com/23968-china-moon-rover-historic-lunar-landing.html.

De Selding Peter B. "Close-Call: Europe's just Launched Sentinel-1A Dodges Dead Satellite." *Space News*, 10 April 2014. Last accessed 5 June 2014. http://www.spacenews.com/article/civil-space/40164close-call-europe%E2%80%99s-just-launched-sentinel-1a-dodges-dead-satellite.

De Selding Peter B. "France Maneuvers Intel Satellite to Avoid Dead Weather Spacecraft." *Space News*, 23 April 2014: A3.

De Selding, Peter B. “Jamming No Mere Nuisance for Middle East Satellite Operators.” *Space News*, 23 March 2012. Last accessed 5 June 2014. http://www.spacenews.com/article/jamming-no-mere-nuisance-middle-east-satellite-operators.

Dorn, Walter. “Paxsat: A Canadian Initiative in Arms Control. Peace Magazine.” Peace Magazine (October-November 1987): 17. Last accessed 9 August 2014. http://peacemagazine.org/archive/v03n5p17.htm.

Emerson, David, Jacques Roy, Sandra Pupatello, and Jim Quick. *Reaching Higher: Canada’s Interests and Future in Space*. Ottawa: Publishing and Depositary Services, 2012. Last accessed 20 February 2014. http://aerospacereview.ca/eic/site/060.nsf/vwapj/Space-e-online.pdf/$file/Space-e-online.pdf.

Fernster, Warren. “U.S., Canadian Governments Sign SSA Data-Sharing Accord.” *Space News*, vol. 25, No. 2, 13 January 2014: 3.

Fernster, Warren. “U.S. Sanctions, Russian Response Fraying Once-Strong Space Ties.” *Space News*, vol. 25, No. 20, 19 May 2014:1,16.

“Final Frontiers.” Asia Pacific Defence Forum, 1 October 2013. Last accessed 5 June 2014. http://apdforum.com/en_GB/article/rmiap/articles/print/features/2013/10/01/feature-pr-9.

Gallaguer, Nancy. “International Cooperation and Space Governance Strategy.” In *Space Strategy in the 21st Century: Theory and Policy,* edited by Eligar Sadeh. New-York: Routledge, 2013: 52-76.

Gallaguer, Nancy. “Space Governance and International Cooperation.” Center for International and Security Studies at Maryland, University of Maryland, 2010. Last accessed: 20 February 2014. http://www.cissm.umd.edu/papers/files/space_governance_and_international_cooperation.pdf.

Garwin, Richard. “Taming Antisatellite and Space Weapons.” *Bulletin of the Atomic Scientists*, 29 May 2007. Last accessed 5 June 2014. http://thebulletin.org/taming-antisatellite-and-space-weapons.

“German space research centre under espionage attack.” *Space Daily*, 3 April 2014. Last accessed 20 February 2014. http://www.spacedaily.com/reports/German_space_research_centre_under_espionage_attack_report_999.html.

Gleeson, Patrick. “Legal Aspects of the Use of Force in Space.” Master thesis, McGill University, 2005.

Godefroy, Andrew. “Is the Sky Falling? Canada’s Defence Space Programme at the Crossroads.” *Canadian Military Journal* (Summer 2000): 51-58.

Godefroy, Andrew. “The Intangible Defence: Canada’s Militarization and Weaponization of Space.” In *The Canadian Way of War: Serving the National Interest*, edited by Bernd Horn. Toronto: Dundurn Press Limited, 2006: 327-357.

Gruss, Mike. “Military Satellite Communications | Panel Ties U.S. Troop Rotations to Satellite Interference Spikes.” *Space News*, 24 June 2013. Last accessed: 5 June 2014.

http://www.spacenews.com/article/military-space/35948military-satellite-communications-panel-ties-us-troop-rotations-to.

Gruss, Mike. “U.S. State Department Says China Conducted an Anti-satellite Test.” *Space News*, vol. 25, No. 31, 4 August 2014: 10.

Gruss, Mike. “With SBSS Follow-on in Limbo, U.S. Space Surveillnce Gap Looms.” *Space News*, vol. 25, No. 8, 24 February 2014:1.

Hays, Peter L. *Space and Security: A Reference Handbook*. Santa Barbara: ABC-CLIO, LLC, 2011.

Helms, Susan. “Schriever Wargame 2010: Thoughts on Deterrence in the Non-Kinetic Domain.” *Air Force Space Command High Frontier*, vol. 7, 1 (November 2010): 12-15.

Hill, Clare. “Satellite and Internet Jamming Worsening.” *Commonwealth Broadcasting Association*, 28 November 2012. Last accessed 9 August 2014. http://www.cba.org.uk/latest/satellite-and-internet-jamming-worsening/.

Honkova, Jana. “The Russian Federation’s Approach to Military Space and Its Military Space Capabilities.” Arlington: The Marshall Institute, November 2013. Last accessed 9 August 2014. http://marshall.org/wp-content/uploads/2013/11/Russian-Space-Nov-13.pdf.

“Israel, India Agree on Missile Defence System Against China.” *World Tribune* (2 April 2014). Last accessed 9 August 2014. http://www.worldtribune.com/2014/04/02/israel-india-agree-on-missile-defense-system-against-china-pakistan-nuclear-strikes/.

Jolly, Claire. “How Secure is Outer Space? Assessing the Threat to Space.” Last accessed 20 February 2014. http://ploughshares.ca/pl_publications/how-secure-is-outer-space-assessing-the-threat-to-space/.

Kehler, C. Robert. “Implementing the National Security Space Strategy.” *Milsat Magazine*, April 2012. Last accessed 20 February 2014. http://milsatmagazine.com/story.php?number=1514333390.

Kleiman, Matthew, and Sonia McNeil. “Red Lines in Outer Space.” *The Space Review*, 5 March 2012. Last accessed 9 August 2014. http://www.thespacereview.com/article/2038/1.

Kramer, Herbert J. “Space-Based Surveillance System.” *Earth Observation Portal*. Last accessed 20 February 2014. https://directory.eoportal.org/web/eoportal/satellite-missions/s/sbss.

Krepon, Michael. “Canada Reclaims its Space.” *Arms Control Wonk*, 14 May 2010. Last accessed 20 February 2014. http://krepon.armscontrolwonk.com/archive/2729/canada-reclaims-its-space.

Krepon, Michael. “Promoting National and Economic Security Interests in Space.” In United States. Department of Defense. *Joint Hearing on the People’s Republic of China’s Counterpace Program and the Implications for U.S. National Security*. House Armed Services Subcommittee on Strategic Forces, 28 Jan 2014. Last accessed 20 February 2014. http://docs.house.gov/meetings/AS/AS29/20140128/101680/HHRG-113-AS29-Wstate-KreponM-20140128.pdf.

Krepon, Michael. “Responding to China’s Counter-space Capabilities.” Stimson Centre, 30 January 2014. Last accessed 20 February 2014. http://www.stimson.org/spotlight/responding-to-chinas-counter-space-capabilities/.

Krepon, Michael. “Waiting for Trouble.” *Space News*, 31 March 2014. Last accessed 5 June 2014. http://www.spacenews.com/article/opinion/40055waiting-for-trouble.

Levitt, Matthew. *Hezbollah: The Global Footprint of Lebanon’s Party of God*. London: C. Hurst & Co, 2013.

Lewis, Jeffrey. “The Role of Non-State Actors in Outer Space Activities. In United Nations Institute for Disarmement Research. *Building the Architecture for Sustainable Space Security - Conference Report 30-31 March 2006*. Vienna, 2006: 31-38.

Lowery, Todd. “Call it MIRACL.” *The Bulletin of the Atomic Scientists* (January/February 1998): 5-6. Last accessed 9 August 2014. https://www.armscontrol.org/act/1997_10/miracloct.

Lowther, Adam. *Deterrence: Rising Powers, Rogue regimes and Terrorism in the Twenty-First Century*. New-York: Palgrave MacMillan, 2012.

Maskell, Paul. “Option Analysis for the Surveillance of Space 2 Project.” Department of National Defence, 16 April 2014.

Maskell, Paul, and Lorne Oram. “Sapphire: Canada’s Answer to Space-Based Surveillance of Orbital Objects.” AMOS Technical Paper, 2008. Last accessed 20 February 2014.

http://www.amostech.com/TechnicalPapers/2008/SSA_and_SSA_Architecture/Maskell.pdf.

Maskell, Paul. “Sapphire: Progress and Status.” Presentation, 21 February 2014.

Oestergaard, Joakim Kasper. “About the WGS Program.” *Barr Group Aerospace*, 27 June 2014. Last accessed 9 August 2014. http://www.bga-aeroweb.com/Defense/Wideband-Global-SATCOM.html.

Philipp, Joshua. “US Alert to China Space Threat.” *Epoch Times*, 7 February 2014. Last accessed 5 June 2014. http://www.theepochtimes.com/n3/493785-us-alert-to-china-space-threat/#?photo=2&_suid=139386667079003522081204420897.

Plait, Phil. “The 50th Anniversary of Starfish Prime: The Nuke that Shook the World.” *Discover Magazine* , 9 July 2012. Last accessed 9 August 2014. http://blogs.discovermagazine.com/badastronomy/2012/07/09/the-50th-anniversary-of-starfish-prime-the-nuke-that-shook-the-world/.

Project Ploushares. *Space Security Index 2013*, edited by Cesar Jaramillo. Kitchener: Pandora Print Shop, 2013. Last accessed 20 February 2014. http://swfound.org/media/121668/SSI_Full_Report_2013.pdf .

Pugliese, David. “Russian Sanctions Have Killed Canadian Satellite Launch.” *Ottawa Citizen*, 23 April 2014. Last accessed 5 June 2014. http://www.ottawacitizen.com/technology/Russian+sanctions+have+killed+Canadian+satellite+launch/9772896/story.html.

RAND Corporation. *Deterrence and First-Strike Stability in Space: A Preliminary Assessment.* Project Air Force, 2010. Last accessed 20 February 2014. http://www.rand.org/content/dam/rand/pubs/monographs/2010/RAND_MG916.pdf.

Rathgeber, Wolfgang, Kai-Uwe Schrogl, and Ray A. Williamson, *The Fair and Responsible Use of Space: An International Perspective*. New York: Springer Wien, 2010.

Razook, Rami R., and Frank C. Belz. "Meeting National Security Space Needs in the Contested Cyberspace Domain." *Aerospace Crosslink Magazine,* Spring 2012. Last accessed 20 February 2014. http://www.aerospace.org/2013/07/26/meeting-national-security-space-needs-in-the-contested-cyberspace-domain/.

Rendleman, James D. "Strategy for Space Assurance." In *Space Strategy in the 21st Century: Theory and Policy,* edited by Eligar Sadeh. New-York: Routledge, 2013: 77-120.

Schmitt, Eric. "Many Sources Feed Taliban's War Chest." *The New York Times*, 18 October 2009. Last accessed 9 August 2014. http://www.nytimes.com/2009/10/19/world/asia/19taliban.html.

Scott, Lauchie. "Orbital Debris Implications Resulting from the ASAT Intercept of 11 January 2007." Technical Report, Defence R&D Canada – Ottawa, December 2007.

Scott, Lauchie, Martin Lévesque, and Stefan Thorsteinson. "Toward Microsatellite Based Space Situational Awareness." AMOS technical Paper, 2013. Last accessed 20 February 2014. http://www.amostech.com/TechnicalPapers/2013/International_Programs/SCOTT.pdf.

Shane, Scott, and David E. Sanger. “Drone Crash in Iran Reveals Secret U.S. Surveillance Effort.” *The New-York Times*, 7 December 2011. Last accessed 9 August 2014. http://www.nytimes.com/2011/12/08/world/middleeast/drone-crash-in-iran-reveals-secret-us-surveillance-bid.html?_r=0.

Sheldon, John B. “Space Power and Deterrence: Are we serious?” Washington, DC: The Marshall Institute, November 2008. Last accessed 20 February 2014. http://marshall.org/wp-content/uploads/2013/08/616.pdf.

Space Foundation. *The Space Report 2012: The Authoritative Guide to Global Space Activity*. Arlington, 2012.

Stokes, Grant H., Curt von Braun, Ramaswamy Sridharan, David Harrison, and Jayant Sharma. “The Space-Based Visible Program.” *MIT Lincoln Laboratory Journal*, vol. 11, no. 2 (1998). Last accessed 5 June 2014. https://www.ll.mit.edu/publications/journal/pdf/vol11_no2/11_2space.pdf.

Tellis, Ashley J. “China’s Counterspace Programs - Only More Bad News.” In United States. Department of Defense. *Joint Hearing on the People’s Republic of China’s Counterpace Program and the Implications for U.S. National Security*. House Armed Services Subcommittee on Strategic Forces, 28 Jan 2014. Last accessed 9 June 2014. http://docs.house.gov/meetings/AS/AS29/20140128/101680/HHRG-113-AS29-Wstate-TellisA-20140128.pdf.

The Center for Strategic and International Studies. *Space Deterrence Workshop Report*. Secure World Foundation, 2010. Last accessed 20 February 2014. http://swfound.org/media/7176/space_deterrence_workshop_report_final.pdf.

The International Institute for Strategic Studies. *The Military Balance 2013*, edited by James Hackett. London: Routledge, March 2013.

Toffler Associates. *Protecting our Space Capabilities: Securing the Future*. Manchester, MA: 2008. Last accessed 9 June 2014. http://www.toffler.com/assets/1/6/2008_-_Protecting_Our_Space_Capabilities_-_Securing_the_Future_080723v2.pdf.

Union of Concerned Scientists. ”USC Satellite Database.” Last accessed 14 August 2014. http://www.ucsusa.org/nuclear_weapons_and_global_security/solutions/space-weapons/ucs-satellite-database.html.

United Nations Committee on the Peaceful Uses of Outer Space. *Status of International Agreements relating to activities in outer space as of 1 January 2014*. Fifty-third session, 24 March to 4 April 2014. Last accessed 20 February 2014. http://www.oosa.unvienna.org/pdf/limited/c2/AC105_C2_2014_CRP07E.pdf.

United Nations Committee on the Peaceful Uses of Outer Space. *Space Debris Mitigation Guidelines*. Last accessed 9 Aug 2014. http://orbitaldebris.jsc.nasa.gov/library/Space%20Debris%20Mitigation%20Guidelines_COPUOS.pdf.

United Nations Conference on Disarmament. “*CD Working Paper: On the Merits of Certain Drafts Transparency and Confidence-Building Measures and Treaty Proposals for Space*

Security." Last accessed 20 February 2014. http://daccess-dds-ny.un.org/doc/UNDOC/GEN/G09/615/92/PDF/G0961592.pdf?OpenElement.

United Nations Conference on Disarmament. *Proposed Prevention of an Arms Race in Outer Space (PAROS) Treaty*. Center for Nonproliferation Studies, 12 March 2012. Last accessed 1 June 2014. http://cns.miis.edu/inventory/pdfs/paros.pdf.

United Nations General Assembly. "Agreement Governing the Activities of States on the Moon and Other Celestial Bodies." In United Nations General Assembly. *Treaties and Principles on Outer Space*. New-York, 2002: 23-30. Last accessed 5 June 2014. http://www.oosa.unvienna.org/pdf/publications/STSPACE11E.pdf.

United Nations General Assembly. "Convention on International Liability for Damage Caused by Space Objects." In United Nations General Assembly. *Treaties and Principles on Outer Space*. New-York, 2002: 11-18. Last accessed 5 June 2014. http://www.oosa.unvienna.org/pdf/publications/STSPACE11E.pdf.

United Nations General Assembly. "Convention on Registration of Objects Launched into Outer Space." In United Nations General Assembly. *Treaties and Principles on Outer Space*. New-York, 2002: 19-22. Last accessed 5 June 2014. http://www.oosa.unvienna.org/pdf/publications/STSPACE11E.pdf.

United Nations General Assembly. *Outer Space Increasingly 'Congested, Contested and Competitive'*. Sixty-eight General Assembly First Committee 17th Meeting. Last accessed 20 February 2014. http://www.un.org/News/Press/docs/2013/gadis3487.doc.htm.

United Nations General Assembly. "The Agreement on the Rescue of Astronauts, the Return of Astronauts and The Return of Objects Launched into Outer Space." In United Nations General Assembly. *Treaties and Principles on Outer Space*. New-York, 2002: 8-10. Last accessed 5 June 2014. http://www.oosa.unvienna.org/pdf/publications/STSPACE11E.pdf.

United Nations General Assembly. *Treaties and Principles on Outer Space*. New-York: 2002. Last accessed 5 June 2014. http://www.oosa.unvienna.org/pdf/publications/STSPACE11E.pdf.

United Nations General Assembly. *Treaty Banning Nuclear Weapon Tests in the Atmosphere, in Outer Space and under Water.* Last accessed 20 February 2014. http://www.un.org/disarmament/WMD/Nuclear/pdf/Partial_Ban_Treaty.pdf.

United Nations General Assembly. "Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies." In United Nations General Assembly. *Treaties and Principles on Outer Space*. New-York, 2002: 3-7. Last accessed 5 June 2014. http://www.oosa.unvienna.org/pdf/publications/STSPACE11E.pdf.

United Nations General Assembly. *United Nations Charter*. Last accessed 20 February 2014. http://www.un.org/en/documents/charter/chapter5.shtml.

United Nations Institute for Disarmament Research. *Space Security Conference 2012 Report*. Last accessed 20 February 2014. http://www.unidir.org/files/publications/pdfs/space-security-2012-en-306.pdf.

United Nations International Telecommunications Union. *Constitution of the International Telecommunications Union*. Last accessed 9 August 2014. http://www.itu.int/dms_pub/itu-s/oth/02/09/s02090000115201pdfe.pdf.

United States. Department of Defense. *An Army at War, Change in the Midst of Conflict*. Proceedings of the Combat Studies Institute, 2005 Military History Symposium. Fort Leavenworth: Combat Studies Institute Press, 2005. Last accessed 9 August 2014. …http://books.google.ca/books?id=8Hkt42314xIC&pg=PA404&dq=Canada+and+Space&hl=en&sa=X&ei=_04NU-vzMtDEqQG3toGYDA&ved=0CE4Q6AEwBjge#v=onepage&q=Canada%20and%20Space&f=false.

United States. Department of Defense and Office of the Director of National Intelligence. *National Security Space Strategy*. Washington, DC: 2011. Last updated 20 February 2014. http://www.defense.gov/home/features/2011/0111_nsss/docs/NationalSecuritySpaceStrategyUnclassifiedSummary_Jan2011.pdf .

United States. Department of Defense. *Desert Storm "Hot Wash" 12-13 July 1991*. Last accessed 9 August 2014. http://www2.gwu.edu/~nsarchiv/NSAEBB/NSAEBB39/document7.pdf.

United States. Department of Defense. *Final Report to Congress: Conduct of the Persian Gulf War*. Washington, DC: April 1992. Last updated 20 February 2014. http://www.dod.mil/pubs/foi/operation_and_plans/PersianGulfWar/404.pdf.

United States. Department of Defense. *Joint Publication 1-02, Dictionary of Military and Associated Terms.* Last updated 15 June 2014. http://www.dtic.mil/doctrine/new_pubs/jp1_02.pdf.

United States. Department of Defense. *Joint Publication 3-14, Space Operations.* Last updated 29 May 2013. http://www.dtic.mil/doctrine/new_pubs/jp3_14.pdf.

United States. Department of Defense. *Resiliency and Disaggregated Space Architecture*. Air Force Space Command White Paper. Washington, DC: 2013. Last accessed 5 June 2014. http://www.afspc.af.mil/shared/media/document/AFD-130821-034.pdf.

United States. Department of Defense. "Space-Based- Space Surveillance." Last updated 26 March 2013. http://www.afspc.af.mil/library/factsheets/factsheet.asp?id=20523.

United States. Department of Defense. Space Track website. Last updated 20 February 2014. https://www.space-track.org/auth/login.

United States. Department of Defense. "USSTRACOM Space Control and Space Surveillance." Last updated January 2014. http://www.stratcom.mil/factsheets/11/Space_Control_and_Space_Surveillance/.

United States. House of Representatives. *Hearing on National Defense Authorizations Act for Fiscal Year 2014 and Oversight of Previously Authorized Programs Before the Committee on Armed Services*, 113th Congress First Session, 25 April 2013. Last accessed 5 June 2014. http://www.gpo.gov/fdsys/pkg/CHRG-113hhrg80769/html/CHRG-113hhrg80769.htm.

United States. National Aeronautics and Space Administration. ”International Space Station: Expedition 40.” Last accessed 5 June 2014. http://www.nasa.gov/mission_pages/station/expeditions/expedition40/.

United States. National Aeronautics and Space Administration. *Orbital Debris Quarterly News*, vol. 18, no. 1 (January 2014). Last accessed 5 June 2014. http://orbitaldebris.jsc.nasa.gov/newsletter/pdfs/ODQNv18i1.pdf.

United States. National Aeronautics and Space Administration. “Orbital Debris Graphics – GEO Images.” Last accessed 9 August 2014. http://orbitaldebris.jsc.nasa.gov/photogallery/beehives.html.

Weeden, Brian. “Through a Glass, Darkly: Chinese, American, and Russian Anti-satellite Testing in Space.” Secure World Foundation, 17 March 2014. Last accessed 20 February 2014. http://swfound.org/media/167224/Through_a_Glass_Darkly_March2014.pdf.

Whitlock, Craig, and Barton Gellman. “U.S. Document Detail Al-Qaeda’s Effort to Fight Back Against Drones.” *The Washington Post*, 3 September 2013. Last accessed 9 August 2014. http://www.washingtonpost.com/world/national-security/us-documents-detail-al-qaedas-efforts-to-fight-back-against-drones/2013/09/03/b83e7654-11c0-11e3-b630-36617ca6640f_story.html.

Zenko, Micah. “Dangerous Space Incidents.” *Council on Foreign Relations, Contingency Planning Memorandum 21* (April 2014). Last accessed 9 August 2014. http://www.cfr.org/space/dangerous-space-incidents/p32790?sp_mid=45655631&sp_rid=dGdyaWV2ZUBuYXRpb25hbGpvdXJuYWwuY29tS0.