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HARNESSING UNMANNED AIRCRAFT SYSTEMS TO ENHANCE CANADIAN ARMED FORCES ANTI-SUBMARINE WARFARE CAPABILITIES

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AIM

1. The aim of this service paper is to recommend that the Royal Canadian Air Force (RCAF) consider pursuing the acquisition and integration of unmanned aircraft systems (UAS) to support Royal Canadian Navy (RCN) and NATO anti-submarine warfare (ASW) operations. In relation to this recommendation, this paper suggests that the RCAF and RCN should investigate optimal methods for the maintenance of sufficient levels of operational readiness in this high-end warfighting sphere.

INTRODUCTION

2. After several decades of apparent calm, the undersea realm is becoming increasingly relevant to contemporary warfare, particularly given progressively more robust anti-access/area denial (A2AD) screens being established by potential adversaries above the water line.[1] This paper outlines historical trends along with contemporary threats and opportunities for Canadian and NATO ASW operations, considers current and future Canadian procurement programs that relate to ASW, and explores the potential for UAS including the nascent Remotely-Piloted Aircraft Systems (RPAS) project to contribute to a more comprehensive Canadian ASW approach going forward.

3. As the RCN and RCAF proceed with an ongoing capitalization of major fleets, Canada is at a crossroads, facing an opportunity to renew its focus on ASW both in terms of defending its extensive maritime and Arctic approaches and remaining a key player in NATO's ability to respond to subsurface threats.

DISCUSSION

4. Given Canada's maritime context, surrounded by three oceans, having the longest coastline in the world and an economy dependent upon the free movement of goods across the global seas, the ability to exert power in the maritime domain is critical for Canada to meet its defence policy objectives. However, as naval analyst Norman Friedman has observed, "[t]he tactical area—often the entire world ocean—on which naval operations can be conducted is vast and trackless. Merely finding ships on that expanse entails enormous effort, both tactically and technologically,"[2] and these difficulties are even more significant when adversary submarines are taken into account.

5. Canada played an important role as a key supporter and innovator in NATO's ASW architecture, which was designed to counter the perceived Soviet submarine threat

[1] Bryan Clark, *The Emerging Era in Undersea Warfare* (Washington: Center for Strategic and Budgetary Assessments, 2015), 1, last accessed 2 February 2021, https://csbaonline.org/research/publications/undersea-warfare.

[2] Norman Friedman, "Navies and Technology," in *The Politics of Maritime Power: A Survey*, ed. Andrew Tan (London: Routledge, 2007), 46.

to sea lines of communication (SLOCs) between North America and Europe during the Cold War.[3] In the years since the end of the Cold War, however, a shift in focus to land-centric operations such as the war in Afghanistan caused Canada and other NATO allies to cut back on specialist ASW capabilities,[4] instead aiming for "broader military capabilities that contribute to national influence across the spectrum of conflict."[5]

6. Recent developments should give reason for pause. In the past five years or so, Russian submarine activity in the North Atlantic in general[6] and the strategically-important Greenland-Iceland-UK (GIUK) gap in particular has increased to levels not seen since before the fall of the Soviet Union.[7] At the same time, despite Russia having a smaller fleet today than it did in 1991, "the quality of its submarines has improved immensely since the 1990s."[8] Farther afield, there has been a "vast proliferation of submarines among Navies in the Asia-Pacific region"[9] since the early 2000s, and as of fall 2020 China is in the process of bolstering shipyard capacity to increase the size of its nuclear submarine fleet.[10] As naval historian Geoffrey Till notes:

> If they wish to matter, to be able to make a difference, to deliver strategic effect, irrespective of their size, navies have to prepare, according to their circumstances, for all three visions of the maritime future: the traditional competitive vision, the cooperative alternative and the newest, bleakest anarchic possibility.[11]

Regardless of how the ostensible present era of renewed inter-state competition plays out, the requirement for Canada to maintain a credible approach to the submarine renaissance is clear.

7. From a technological standpoint, observers have long heralded the impending end of the submarine era, suggesting that new sensors would soon render the sea

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[3] Marc Milner, *Canada's Navy: The First Century* (Toronto: University of Toronto Press, 1999), x.

[4] Peter Sproule, "Canada and the Fourth Battle of the Atlantic," *Canadian Naval Review* 16, no. 3 (2021): 5.

[5] Peter Hudson and Peter Roberts, "The UK and the North Atlantic: A British Military Perspective," in *NATO and the North Atlantic: Revitalising Collective Defence*, ed. John Andreas Olsen (Abingdon: Royal United Services Institute for Defence and Security Studies, 2017), 83.

[6] Michael Peel and David Bond, "NATO Sounds Alarm on Russian Submarine Activity," *Financial Times*, 22 December 2017, last Accessed 2 February 2021, https://www.ft.com/content/40236a0a-e711-11e7-97e2-916d4fbac0da.

[7] John J. Hamre and Heather A. Conley, "The Centrality of the North Atlantic to NATO and US Strategic Interests," in *NATO and the North Atlantic: Revitalising Collective Defence*, ed. John Andreas Olsen (Abingdon: Royal United Services Institute for Defence and Security Studies, 2017), 50-51.

[8] Sproule, "Canada and the Fourth Battle of the Atlantic," 5.

[9] Department of National Defence, *The Future Security Environment, 2013-2040* (Ottawa: Chief of Force Development, 2014), 113.

[10] H.I. Sutton, "Chinese Increasing Nuclear Submarine Shipyard Capacity," *USNI News*, 12 October 2020, https://news.usni.org/2020/10/12/chinese-increasing-nuclear-submarine-shipyard-capacity.

[11] Geoffrey Till, "Small Navies in the Current Strategic Context," in *Europe, Small Navies and Maritime Security: Balancing Traditional Roles and Emergent Threats in the 21st Century*, ed. Robert McCabe, Deborah Sanders and Ian Speller (London: Routledge, 2020), 17.

"transparent."[12] While the ubiquity of space-based surveillance using a wide variety of sensors has made it near impossible for military forces to avoid detection on land or above the waterline, the undersea realm remains one of the last relatively safe havens due to the many obstacles to achieving persistent and accurate surveillance, "transparent ocean" predictions notwithstanding.[13] Furthermore, rising ocean temperatures stemming from anthropogenic climate change coupled with increasing levels of ocean noise are rendering the acoustic sensing of submarines more difficult.[14] While non-acoustic means of detecting submarines may be a game changer in the future, as of yet they have not yet developed sufficiently to preordain submarines (and ASW) to irrelevance.[15]

8. In light of global military and technological trends, Canada and other NATO member states including the United States have begun to recognize the need to bolster ASW capacity and capability in recent years.[16] Though Canada's most recent defence policy[17] does not mention ASW in particular, the requirement to provide surveillance of and response to subsurface threats remains a core component of the defence of Canada[18] and in terms of the ability to project expeditionary maritime power.[19] Furthermore, the draft CAF *Pan-Domain Force Employment Concept* (PFEC) explicitly recognizes the need to expand CAF capability to track submarines in response to increasing adversary challenges in the maritime domain.[20]

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[12] See, for example, Walter Sullivan, "Can Submarines Stay Hidden?" *The New York Times*, 11 December 1984, https://www.nytimes.com/1984/12/11/science/can-submarines-stay-hidden.html. For a more recent version of this line of argument, see David Hambling, "The Inescapable Net: Unmanned Systems in Anti-Submarine Warfare," BASIC Parliamentary Briefings on Trident Renewal, March 2016, https://basicint.org/publications/david-hambling/2016/inescapable-net-unmanned-systems-anti-submarine-warfare.

[13] Hudson and Roberts, "The UK and the North Atlantic," 83.

[14] Daniel Kelly, "Sonar in Warming Oceans Put to Test," *Environmental Monitor*, 20 June 2016, https://www.fondriest.com/news/sonar-warming-oceans-put-test.htm. See also Brooks Hays, "Scientists, Navy Consider Future of Sonar in Warming Oceans," *UPI*, 25 May 2016, https://www.upi.com/Science_News/2016/05/25/Scientists-Navy-consider-future-of-sonar-in-warming-oceans/1151464191484/.

[15] Bradford Dismukes, "The Return of Great Power Competition: Cold War Lessons about Strategic Antisubmarine Warfare and Defense of Sea Lines of Communication," *Naval War College Review* 73, no. 3 (2020): 54.

[16] William A. Perkins, "Unmanned Air Systems in NATO Anti-Submarine Warfare (ASW): Potential Future Applications and Concepts," *Journal of the Joint Air Power Competence Centre* 25 (Winter 2017/2018): 27; Sproule, "Canada and the Fourth Battle of the Atlantic," 4; and Dismukes, "The Return of Great-Power Competition," 39, 49.

[17] Department of National Defence, *Strong, Secure, Engaged: Canada's Defence Policy* (Ottawa: Her Majesty the Queen in Right of Canada, 2017).

[18] The Canadian Joint Operations Command (CJOC) Operations Order for Op LIMPID, for example, outlines an operational objective that in terms of Canada's approaches, "[v]essels (aircraft, ships, submarines, and land vehicles) deemed hostile are detected and tracked." Department of National Defence, Operation Order LIMPID (Ottawa: Canadian Joint Operations Command, 7 June 2016) RDIMS #396366, https://collaboration-cjoc-coic.forces.mil.ca/sites/OpLIMPID/ApprovDoc/Forms/AllItems.aspx.

[19] Department of National Defence, *Leadmark 2050: Canada in a New Maritime World* (Ottawa: Royal Canadian Navy, 2016).

[20] Department of National Defence, *Pan-Domain Force Employment Concept: Prevailing in an Uncertain World* [draft] (Ottawa: Her Majesty the Queen in Right of Canada, 2020), 4, 24.

9. Within the CAF, both the RCN and the RCAF have acknowledged the need to cooperate and to embrace technological innovation as a means of ensuring Canada is able to remain relevant in combating emerging threats, including the burgeoning submarine threat. In particular, unmanned systems are seen by both the RCN[21] and the RCAF[22] as critical enablers. In 2013, for example, the RCN crafted a concept document for ASW which stated that "[t]he Navy and Air Force should liaise in order to develop tactics and employment of future manned and unmanned aviation assets to ensure efficient ASW operations,"[23] but due to the slow advance of acquisition projects for UAS, much is still yet to be done on this front.

10. At present, both the RCN and the RCAF are in the midst of significant fleet recapitalizations that are relevant to the conduct of ASW. Though the paying off of the *Protecteur*-class auxiliary oiler replenishment (AOR) and *Iroquois*-class destroyers were significant blows to the RCN during the past decade, the modernization and extension of the *Halifax*-class frigates and the operation of *Victoria*-class submarines have helped to ensure an adequate level of ASW capability can be retained by the RCN until the Canadian Surface Combatant arrives. With the recent replacement of the CH124 Sea King with the CH148 Cyclone, the RCAF is now able to provide a modern and capable maritime helicopter (MH) to provide organic shipborne support to RCN operations after years of tactical near-obsolescence. In addition, the CP140 Block IV project is bringing Canada's maritime patrol aircraft (MPA) fleet up to date with modernized capabilities including upgraded sensors and datalink. That being said, like the surface fleet of the RCN, both the MH and MPA fleets of the RCAF are numerically much smaller now than during the Cold War. For both of these fleets, meeting the potentially increasing demands of high-end ASW operations with a smaller fleet and broader mission set will be a challenge. Further, the Canadian Multi-Mission Aircraft (CMMA) project, which is working to procure a replacement for the CP140, is not slated to deliver until the mid-2030s, and neither a significant increase in fleet size nor a return to specialization in ASW appears likely.

11. In order to address this foreseeable delta between ASW capacity and requirement, it would be prudent for both the RCN and the RCAF to explore some ways that UAS could contribute to ASW in the near- to medium-term future. As noted in RCAF Intelligence, Surveillance and Reconnaissance (ISR) doctrine, "UAS are ideally suited for collection missions that are long and tedious (dull), hazardous to humans (dangerous) or are carried out in undesirable conditions (dirty),"[24] all of which generally apply to ASW missions, and are particularly relevant in terms of the farthest regions of Canada's maritime approaches. Indeed, as U.S. Navy Captain William Perkins has observed:

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[21] DND, *Leadmark 2050*, 57.

[22] Department of National Defence, *Future Concepts Directive Part 2: Future Air Operating Concept* (Ottawa: Royal Canadian Air Force, 2016), 22.

[23] Department of National Defence, *Concept for Anti-Submarine Warfare* (Ottawa: Director General Maritime Force Development, 2013), https://collaboration-navy.forces.mil.ca/sites/DNavStrat/Endorsed%20Concepts/Forms/AllItems.aspx.

[24] Department of National Defence, B-GA-401-002/FP-001, *Royal Canadian Air Force Doctrine: Intelligence, Surveillance and Reconnaissance*, 2nd ed. (Ottawa: Royal Canadian Air Force, 2017), 17.

> Specific to ASW … an unmanned system could conduct certain time-consuming functions, such as loitering in a designated search location to monitor the ocean and conduct initial detection of a submarine moving through the area … [which] remains the most critical link in the ASW kill chain.[25]

In addition to exploiting the air power tenet of persistence as identified in RCAF doctrine,[26] UAS in an ASW role would limit the risk to human operators. Particularly given recent advances in submarine-launched surface-to-air missiles (SubSAM) that make traditional airborne ASW based upon MH and MPA significantly more dangerous to aircrew in close proximity to hostile submarines,[27] augmenting manned ASW assets with UAS shows promising potential to re-balance the math of dealing with subsurface threats. Moreover, the lower upfront and operating costs of UAS compared to traditional manned platforms could enable a more efficient use of ASW resources while amplifying potential operational effects.[28]

12. While UAS have had some drawbacks that have limited their employment in ASW to this point, many of the most common objections to their employment in such a role have been overcome in recent years. When former Canadian Chief of the Maritime Staff Vice Admiral (ret'd) Drew Robertson spoke to Canadian parliamentarians in 2016 about the viability of UAS in the ASW role, for example, he was circumspect, suggesting that "they do not have acoustic capabilities, and that's what one really needs at sea."[29] With the recent addition of sonobuoy dispensing pods, along with other sensors like magnetic anomaly detectors (MAD), to a variety of UAS, such an objection no longer holds water. That being said, the significant bandwidth requirements associated with communicating acoustic data for processing,[30] particularly beyond line of sight (BLOS), suggests that UAS would still generally be better suited to work in concert with manned aircraft (along with manned and unmanned vessels) rather than serving as any sort of wholesale replacement for manned ASW aircraft.[31]

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[25] Perkins, "Unmanned Air Systems," 28.

[26] Department of National Defence, B-GA-400-000/FP-001, *Royal Canadian Air Force Doctrine*, 3rd ed. (Ottawa: Royal Canadian Air Force, 2016), 17.

[27] For an overview of SubSAM technological advances and the threats they pose to aircrew, see David Downie, "Future Sub-Surface Threats" (Joint Command and Staff Programme Service Paper, Canadian Forces College, 2020). See also Tyler Rogoway, "Have Submarine-Launched Anti-Aircraft Missiles Finally Come of Age?" *The War Zone* (blog), 10 January 2017, https://www.thedrive.com/the-war-zone/6894/have-submarine-launched-anti-aircraft-missiles-finally-come-of-age.

[28] Caleb Larsen, "U.S. Reaper Drones a New Mission: Sub Hunting," *The National Interest*, 19 January 2021, https://nationalinterest.org/blog/buzz/us-reaper-drones-new-mission-sub-hunting-176668.

[29] Quoted in Parliament of Canada, *The Readiness of Canada's Naval Forces: Report of the Standing Committee on National Defence* (Ottawa: House of Commons Standing Committee on National Defence, 2017), 69.

[30] Perkins, "Unmanned Air Systems," 28.

[31] Chinese naval researchers have arrived at a similar conclusion regarding the optimal potential of "hybrid formations" of manned and unmanned platforms in conducting ASW. Xu Liang, Pan Zuanhong, and Wu Ming, "Analysis on Manned/Unmanned Aerial Vehicle Cooperative Operation in Antisubmarine Warfare," *Chinese Journal of Ship Research* 13, no. 6 (2018): 154-159.

13. After a prolonged and punctuated beginning to its procurement process, Canada's RPAS project is finally getting off the ground, having completed an Invitation to Qualify that has resulted in two qualified suppliers being identified as eligible for bid submission.[32] With a final Request for Proposals due out in the coming months, the RPAS project is seeking to deliver a medium-altitude long-endurance (MALE), armed multi-mission RPAS capable of providing "all weather, day/night ISR, targeting and SIGINT of land/sea targets" for both domestic and expeditionary operations.[33] At this point, it appears that the focus will be on surface vessels in the maritime domain rather than submarines, but the candidate platforms of both of the project's qualified suppliers have demonstrated ASW capabilities that could be added as options post-contract award. The General Atomics MQ-9B has undergone successful trials to demonstrate its capacity to track subsurface targets using sonobuoys,[34] and the Israel Aerospace Industries Heron TP can reportedly be equipped with both sonobuoys and MAD sensors.[35] In addition, both aircraft can be fitted with maritime search radar and Automatic Identification System (AIS),[36] which coupled with a mix of ISR sensors including Electro-Optical/Infrared (EO/IR) and Synthetic Aperture Radar (SAR) offers versatility in contributing to the ASW fight. Finally, given the payload capacity of both aircraft, the addition of small (200-pound) torpedoes like those being pursued by the Very Light-Weight Torpedo program of the U.S. Navy could be a future capability.[37]

14. Whether as an augmentation to the capabilities of the planned RPAS fleet through the addition of sensors and mission types or as an acquisition of additional dedicated aircraft and associated enablers, MALE RPAS are well-suited to enable a layered CAF and NATO approach to ASW that meets the demands of the contemporary and future threat environment. While the current RPAS project should not be interrupted at this point due to the already significant delays the project has encountered in delivering relevant unmanned aircraft for the RCAF, effort should be directed toward ensuring RPAS are able to contribute to ASW operations following award of the RPAS contract.

15. In addition to RPAS, other UAS should continue to be explored by Canada for their potential usage in ASW. In particular, the development of air-launchable ASW-

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[32] Public Services and Procurement Canada (PSPC), "Remotely-Piloted Aircraft Systems (RPAS) – Information for Canadian Industry (Ottawa: PSPC, 22 June 2020), last accessed 2 February 2021, https://buyandsell.gc.ca/procurement-data/tender-notice/PW-RPS-002-27808.

[33] PSPC, RPAS Information for Canadian Industry.

[34] Garrett Reim, "General Atomics MQ-9's Anti-Submarine Tracking Capability," *FlightGlobal*, 19 January 2021, https://www.flightglobal.com/military-uavs/general-atomics-demos-mq-9s-anti-submarine-tracking-capability/142032.article.

[35] Vayu Aerospace & Defence Review, "Year of the IAI Heron TP UAV," last accessed 2 February 2021, https://www.vayuaerospace.in/article/598/index.aspx.

[36] General Atomics Aeronautical, "Team SkyGuardian Canada: MQ-9B SkyGuardian," last accessed 4 February 2021, https://www.ga-asi.com/teamskyguardiancanada/mq-9b; Vayu Aerospace & Defence Review, "Year of the IAI Heron TP UAV."

[37] Richard R. Burgess, "Northrop Grumman to Bid on Navy's Very Light-Weight Torpedo Program," *SeaPower*, 9 December 2020, https://seapowermagazine.org/northrop-grumman-to-bid-on-navys-very-light-weight-torpedo-program/.

capable UAS[38] should be considered in the refinement of requirements for the CMMA project. Along similar lines, the RCN Intelligence, Surveillance, Target Acquisition and Reconnaissance (ISTAR) UAS project offers the potential to reduce demand on MH by providing additional ISR capability from a small shipborne UAS,[39] particularly for anti-surface warfare (ASuW), but the limited payload capacity of such small UAS may inhibit full integration into ASW operations for the time being. Nonetheless, as identified in *Leadmark 2050*, the RCN should continue to explore options for shipborne UAS (along with other unmanned systems including underwater and surface vehicles) to contribute to maritime warfare including ASW as technology matures.[40]

16. In any case, the acquisition of unmanned platforms is a prudent, but not sufficient, step along the path to a renewed high-level ASW capability for Canada, both domestically and as a contributor to NATO and expeditionary operations. Along with assets and crew-level competencies, though, perhaps the more significant task will be successfully integrating the various systems and exercising to the level of theatre ASW.[41] For RCAF aircraft (CH148, CP140, CMMA, RPAS), this will be a challenge due to the extensive mission sets (ISR, SAR, utility, ASW, ASuW, precision strike, etc.) of each platform. Consequently, force generation demands at the tactical and operational levels will continue to be significant for all players in ASW. As such, specialization by crew or by geographic location may need to be considered for each of the multi-mission aircraft fleets involved in ASW in order to ensure the development of a core cadre of skilled practitioners.

CONCLUSION

17. In an uncertain international environment, submarines remain a relevant and potent threat. Given this enduring relevance of the subsurface threat, Canada must maintain and enhance ASW capabilities to ensure the CAF can respond accordingly. As fleets of ships and aircraft are being recapitalized, Canada must harness this once-in-a-generation opportunity to re-imagine the CAF approach to ASW by embracing technological innovation. Specifically, the potential of UAS should be taken seriously as part of a comprehensive approach to ensuring Canadian defence objectives are met with a robust suite of ASW capabilities.

18. Specifically, given the increasing viability of ASW-capable RPAS and smaller UAS, Canada should strive to buttress extant ASW capabilities with those that could be

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[38] For example, small UAS equipped with MAD booms, which could be launched from an MPA platform. See John Keller, "Industry Asked to Develop Magnetic Anomaly Detector (MAD)-Equipped UAV for Anti-Submarine Warfare (ASW)," *Military Aerospace & Electronics*, 12 June 2019, https://www.militaryaerospace.com/unmanned/article/14034795/antisubmarine-warfare-asw-uav-magnetic-anomaly-detector-mad.

[39] Public Services and Procurement Canada, "Royal Canadian Navy Intelligence, Surveillance, Target Acquisition and Reconnaissance Unmanned Aircraft System Project System Performance Specification," last accessed 3 February 2021, https://buyandsell.gc.ca/procurement-data/tender-notice/PW-QD-050-28078.

[40] DND, *Leadmark 2050*.

[41] Sproule, "Canada and the Fourth Battle of the Atlantic," 7.

offered by RPAS and other UAS to enable persistent surveillance of sub-surface threats in Canada's maritime and Arctic approaches along with enhanced deployable ASW capability to support NATO and coalition partners on expeditionary operations.

19. Considering the myriad multi-mission demands on current and future fleets of maritime helicopters and patrol aircraft, the integration of RPAS and UAS must be considered carefully to ensure an appropriate level of proficiency from the operator level to the higher-level coordination of theatre ASW.

RECOMMENDATIONS

20. It is recommended that Director Air Requirements:

a. explores follow-on options to augment the ASW capability of the future RPAS fleet by the addition of acoustic and/or MAD sensors; and

b. considers the potential to add a requirement for air-launchable ASW UAS to the CMMA project.

21. Recognizing that high-end ASW comes with significant force generation requirements, it is recommended that 1 Canadian Air Division Director Fleet Readiness investigate optimal methods of maintaining skills of ASW aircrew, in particular by:

a. studying the viability of crew specialization by capability or geographic location for each fleet that may contribute to ASW operations (CH148, CP140, CMMA, and RPAS); and

b. exploring the effectiveness of managed readiness cycles or other innovative models to ensure sufficient numbers of operators are current and proficient in high-end ASW tasks when required.

22. Finally, given the joint focus between the RCN and RCAF that will be necessary to ensure a high level of tactical and operational competence in ASW, it is recommended that the RCAF Aerospace Warfare Centre and the Canadian Forces Maritime Warfare Centre collaborate to:

a. study the employment of UAS as part of a system of systems approach to ASW operations; and

b. consider methods to optimize collective ASW training opportunities up to the theatre ASW level in order to inform RCAF and RCN force posture and readiness.

BIBLIOGRAPHY

Abraham, J.P., M. Baringer, N.L. Bindoff, T. Boyer, L.J. Cheng, J.A. Church, J.L. Conroy, C.M. Domingues, J.T. Fasullo, J. Gilson, G. Goni, S.A. Good, J.M. Gorman, V. Gouretski, M. Ishii, G.C. Johnson, S. Kizu, J.M. Lyman, A.M. Macdonald, W.J. Minkowycz, S.E. Moffitt, M.D. Palmer, A.R. Piola, F. Reseghetti, K. Schuckmann, K.E. Trenberth, I. Velicogna, and J.K. Willis. "A Review of Global Ocean Temperature Observations: Implications for Ocean Heat Content Estimates and Climate Change." *Reviews of Geophysics* 51 (2013): 450-483.

Burgess, Richard R. "Northrop Grumman to Bid on Navy's Very Light-Weight Torpedo Program." *SeaPower*, 9 December 2020. https://seapowermagazine.org/northrop-grumman-to-bid-on-navys-very-light-weight-torpedo-program/.

Canada. Department of National Defence. B-GA-401-002/FP-001, *Royal Canadian Air Force Doctrine: Intelligence, Surveillance and Reconnaissance*. 2nd ed. Ottawa: Royal Canadian Air Force, 2017.

———. "Concept for Anti-Submarine Warfare." Ottawa: Director General Maritime Force Development, 2013. https://collaboration-navy.forces.mil.ca/sites/DNavStrat/Endorsed%20Concepts/Forms/AllItems.aspx.

———. "Concept for Maritime Unmanned Systems." Ottawa: Director General Naval Force Development, 2016. https://collaboration-navy.forces.mil.ca/sites/DNavStrat/Endorsed%20Concepts/Forms/AllItems.aspx.

———. *Future Concepts Directive Part 2: Future Air Operating Concept*. Ottawa: Royal Canadian Air Force, 2016.

———. *The Future Security Environment, 2013-2040*. Ottawa: Chief of Force Development, 2014.

———. *Leadmark 2050: Canada in a New Maritime World*. Ottawa: Royal Canadian Navy, 2016.

———. Operation Order LIMPID. Ottawa: Canadian Joint Operations Command, 7 June 2016. RDIMS #396366. https://collaboration-cjoc-coic.forces.mil.ca/sites/OpLIMPID/ApprovDoc/Forms/AllItems.aspx.

———. *Pan-Domain Force Employment Concept: Prevailing in an Uncertain World* [draft]. Ottawa: Her Majesty the Queen in Right of Canada, 2020.

———. *RCAF Vectors*. Ottawa: Director General Air Readiness, 2019.

———. *Strong, Secure, Engaged: Canada's Defence Policy*. Ottawa: Her Majesty the Queen in Right of Canada, 2017.

Canada. Parliament of Canada. *The Readiness of Canada's Naval Forces: Report of the Standing Committee on National Defence*. Ottawa: Standing Committee on National Defence, June 2017. https://www.ourcommons.ca/Content/Committee/421/NDDN/Reports/RP9031883/nddnrp06/nddnrp06-e.pdf.

Canada. Public Services and Procurement Canada. Remotely Piloted Aircraft Systems (RPAS) – Information for Canadian Industry. Ottawa: PSPC, 22 June 2020. Last accessed 2 February 2021. https://buyandsell.gc.ca/procurement-data/tender-notice/PW-RPS-002-27808.

———. Royal Canadian Navy Intelligence, Surveillance, Target Acquisition and Reconnaissance Unmanned Aircraft System Project System Performance Specification. Last accessed 3 February 2021. https://buyandsell.gc.ca/procurement-data/tender-notice/PW-QD-050-28078.

Clark, Bryan. *The Emerging Era in Undersea Warfare*. Washington: Center for Strategic and Budgetary Assessments, 2015. Last accessed 2 February 2021. https://csbaonline.org/research/publications/undersea-warfare.

Dismukes, Bradford. "The Return of Great-Power Competition: Cold War Lessons about Strategic Antisubmarine Warfare and Defense of Sea Lines of Communication." *Naval War College Review* 73, no. 3 (2020): 39-63.

Downie, David. "Future Sub-Surface Threats." Joint Command and Staff Programme Service Paper, Canadian Forces College, 2020.

Friedman, Norman. "Navies and Technology." In *The Politics of Maritime Power: A Survey*, edited by Andrew Tan, 45-61. London: Routledge, 2007.

General Atomics Aeronautical. "Team SkyGuadrian Canada: MQ-9B SkyGuardian." Last accessed 4 February 2021, https://www.ga-asi.com/teamskyguardiancanada/mq-9b.

Hambling, David. "The Inescapable Net: Unmanned Systems in Anti-Submarine Warfare." BASIC Parliamentary Briefings on Trident Renewal, March 2016. https://basicint.org/publications/david-hambling/2016/inescapable-net-unmanned-systems-anti-submarine-warfare.

Hamre, John J., and Heather A. Conley. "The Centrality of the North Atlantic to NATO and US Strategic Interests." In *NATO and the North Atlantic: Revitalising Collective Defence*, edited by John Andreas Olsen, 47-59. Abingdon: Royal United Services Institute for Defence and Security Studies, 2017.

Hays, Brooks. “Scientists, Navy Consider Future of Sonar in Warming Oceans.” *UPI*, 25 May 2016. https://www.upi.com/Science_News/2016/05/25/Scientists-Navy-consider-future-of-sonar-in-warming-oceans/1151464191484/.

Hudson, Peter, and Peter Roberts. “The UK and the North Atlantic: A British Military Perspective.” In *NATO and the North Atlantic: Revitalising Collective Defence*, edited by John Andreas Olsen, 73-85. Abingdon: Royal United Services Institute for Defence and Security Studies, 2017.

Keller, John. “Industry Asked to Develop Magnetic Anomaly Detector (MAD)-Equipped UAV for Anti-Submarine Warfare (ASW).” *Military & Aerospace Electronics*, 12 June 2019. https://www.militaryaerospace.com/unmanned/article/14034795/antisubmarine-warfare-asw-uav-magnetic-anomaly-detector-mad.

Kelly, Daniel. “Sonar in Warming Oceans Put to Test.” *Environmental Monitor*, 20 June 2016. https://www.fondriest.com/news/sonar-warming-oceans-put-test.htm.

Larsen, Caleb. “U.S. Reaper Drones a New Mission: Sub Hunting.” *The National Interest*, 19 January 2021. https://nationalinterest.org/blog/buzz/us-reaper-drones-new-mission-sub-hunting-176668.

Peel, Michael, and David Bond. “NATO Sounds Alarm on Russian Submarine Activity.” *Financial Times*, 22 December 2017. Last Accessed 2 February 2021. https://www.ft.com/content/40236a0a-e711-11e7-97e2-916d4fbac0da.

Perkins, William A. “Unmanned Air Systems in NATO Anti-Submarine Warfare (ASW): Potential Future Applications and Concepts.” *Journal of the Joint Air Power Competence Centre* 25 (Winter 2017/2018): 27-33.

Reim, Garrett. “General Atomics Demos MQ-9’s Anti-Submarine Tracking Capability.” *FlightGlobal*, 19 January 2021. https://www.flightglobal.com/military-uavs/general-atomics-demos-mq-9s-anti-submarine-tracking-capability/142032.article.

Rogoway, Tyler. “Have Submarine-Launched Anti-Aircraft Missiles Finally Come of Age?” *The War Zone* (blog), 10 January 2017, https://www.thedrive.com/the-war-zone/6894/have-submarine-launched-anti-aircraft-missiles-finally-come-of-age.

Sproule, Peter. “Canada and the Fourth Battle of the Atlantic.” *Canadian Naval Review* 16, no. 3 (2021): 4-8.

Sullivan, Walter. “Can Submarines Stay Hidden?” *The New York Times*, 11 December 1984. https://www.nytimes.com/1984/12/11/science/can-submarines-stay-hidden.html.

Sutton, H.I. “Chinese Increasing Nuclear Submarine Shipyard Capacity.” *USNI News*, 12 October 2020, https://news.usni.org/2020/10/12/chinese-increasing-nuclear-submarine-shipyard-capacity.

Till, Geoffrey. “Small Navies in the Current Strategic Context.” In *Europe, Small Navies and Maritime Security: Balancing Traditional Roles and Emergent Threats in the 21st Century*, edited by Robert McCabe, Deborah Sanders and Ian Speller, 15-25. London: Routledge, 2020.

Vayu Aerospace & Defence Review. “Year of the IAI Heron TP UAV.” Last accessed 2 February 2021, https://www.vayuaerospace.in/article/598/index.aspx.

Xu Liang, Pan Zuanhong, and Wu Ming. “Analysis on Manned/Unmanned Aerial Vehicle Cooperative Operation in Antisubmarine Warfare.” *Chinese Journal of Ship Research* 13, no. 6 (2018): 154-159.