Niobe Papers No. 11

Autonomous Underwater Vehicles

A Future Capability for the RCN

Commander Mark O'Donohue

This paper was originally published in 2016 as a Joint Command and Staff Programme 42 (JCSP) Service Paper at the Canadian Forces College, Toronto. It has been edited and reproduced here as part of an ongoing partnership between the CFC and the NAC to bring forward some of the best work in the field of maritime security to both inform and provoke discussion.

In an effort to obtain oceanographic data along precise trajectories, scientists working at the Applied Physics Laboratory of the University of Washington invented the first Autonomous Underwater Vehicle (AUV) in the 1950s.[1] Since that time, research and development of AUVs – for both commercial and military applications – has significantly expanded, moving these craft from the realm of science experiments to practical tools. As their capability expands and AUVs become increasingly common and robust, the Royal Canadian Navy (RCN) will need to follow other states in integrating them into the fleet.

Integration will take time. Despite the progress that has been made in recent years, AUVs remain a novel technology, requiring years of research and development before they can become operational. As such, the time to act is now, with the onus for initiative on Defence Research and Development Canada (DRDC), which needs to begin laying the groundwork for AUV deployment as soon as possible. Canada's diverse maritime security requirements and its enormous ocean space should make this initiative a priority.

Meeting the country's diverse needs requires flexibility and adaptability in its platforms and systems and, in an AUV, the navy will require a collaborative multi-purpose system capable of naval mine countermeasures (NMCM) and passive anti-submarine warfare (ASW); and, somewhat unique to Canada, it will have to have a cold-water Arctic capability. Flexible AUVs will have to be deployable from a ship or an aircraft, in support of both military and whole-of-government operations. The technical challenges to deploying something like this will be significant but this kind of next generation system may represent the future of naval operations and Canada cannot be left behind.

Developing AUVs

Improvements in AUV technology have quickened in recent years as engineers from around the world compete to bring this next-generation technology to its full potential. The world's major navies have invested in this research and made clear their interest in AUVs as a long-term priority. The US Navy is working on its prototype Boeing Orca craft while the contract for the

Royal Navy's Manta system was awarded MSubs Ltd in 2020. While Canada is not at the advanced prototyping phase, it has clearly established an interest in following suit, experimenting with minor craft and developing the underlying technology.

This path was laid out in 2013 through the *Commander's Guidance and Direction to the Royal Canadian Navy: Executive Plan 2013-2017*. In that guidance document, Vice-Admiral Mark Norman connected RCN planning priorities with specific strategic and national objectives.[2] In response to the government of Canada's geopolitical aim of employing the RCN as an instrument of national power in dealing with maritime security at home and abroad, Vice-Admiral Norman stated that the RCN "must identify ways to deploy more persistently in regions of strategic interest."[3] That persistent deployment would be facilitated through the use of low-cost, unmanned systems. In particular, such systems would make operations in the Arctic significantly easier and safer.[4] Following this and other strategic direction, the Director General of Naval Force Development staff created a *Concept for Maritime Unmanned Systems*, which provides overarching guidance for the development of unmanned vehicles within the RCN, broadly defining them as: "systems operated by or on behalf of maritime force elements, performing their activity in the maritime environment (air, surface, subsurface) . . . whose primary component is at least one unmanned vehicle."[5] It identifies AUVs as a subcategory of Maritime Unmanned Systems, conceptualising them as "physically independent vehicles capable of conducting their own tasks with or without external control."[6] This concept supports Vice-Admiral Norman's direction as it envisions the RCN acquiring, integrating and exploiting "unmanned systems to both enhance existing maritime capabilities and potentially provide new ones."[7]

The Maritime Unmanned Systems concept document is intended for use in force development as a reference for further inquiry, as it "serves as a guide for the development of . . . requirements and projects, and supports the generation and employment" of future capabilities.[8] This document also outlines the way in which force developers should inform and prioritise future "decisions on research, experimentation, design, acquisition, tactical development, personnel employment, and training."[9] Recognising that "there is no significant body of opinion arguing against greater use of unmanned systems in the future," the concept document states that force developers need to focus their attention on how these systems can "better meet the needs of Future Fleet."[10] It specifically directs them to consider coverage, flexibility, reduced risk and cost, as planning factors when procuring unmanned systems.[11]

Options for Canada

In the years since the RCN began that work a series of small-scale experiments have been undertaken. In 2016 Canada participated in Exercise Unmanned Warrior led by the Royal Navy at the British Underwater Test and Evaluation Centre in Scotland. In what was one of the largest demonstrations of unmanned vehicles ever DRDC's team brought three vehicles: two AUVs called IVER3 UUV, and one surface vehicle called the USV-2600. Both torpedo-shaped free-swimming underwater robots, have side-scan sonars which use acoustic waves to take images of the seafloor, making them ideal mine hunters. The surface vehicle is able to communicate with the submerged vehicles to relay their detection information to a circling unmanned aerial vehicle, which can relay the information over to a command and control ship or facility.[12]

The RCN also recently acquired its first REMUS 100s through the Maritime Operations Group's Fleet Diving Unit (Atlantic). These small commercial systems can be used for surveillance and mine hunting. DRDC is also testing the larger ThunderFish AUVs, built by Kraken Robotics. The purpose of these commercial systems is ultra-high-resolution seabed imaging and mapping applications, though the defence applications are clear. These craft might one day fulfill the role of naval mine countermeasures (NMCM) AUVs, allowing support ships to remain at a safe stand-off while the AUV conducts its survey mission for mine-like objects.[13] Moving from these limited systems to something more capable is the next step.

One such option might come from researchers from the Department of Computer Engineering at the University of Girona in Spain, who have developed a multi-purpose AUV capable of being reconfigured to conduct different tasks.[14] For example, the Girona 500 could be easily deployed from and controlled by a ship. It is a lightweight aluminum vehicle composed of multiple streamlined hulls held together by a light frame.[15] This particular design represents a compromise between the low drag hydrodynamics of torpedo-shaped vehicles and the simplicity and stability of open frame platforms, thereby making it a versatile vehicle.[16] In addition, the Girona 500 is equipped with layer-based software – referred to as the Component Orientated Layer-based Architecture – allowing it to be reconfigured for different missions and tasks.[17] This capability coincides with the vision outlined in the RCNs guidance documents, that: "[f]uture systems may be multi-purpose and be able to provide information to support different needs."[18] However, despite the fact that this AUV meets some of the Canadian requirements for flexibility, it does not satisfy the RCN's requirement for coverage. As well, the Girona 500 has not been tested in Arctic-like conditions, and therefore does not meet the requirement of having "the potential to extend mission duration and operate in harsher environmental conditions."[19] Nor has it been specifically tested to conduct military missions such as passive ASW and NMCM operations.

Meeting some of these needs could come from work undertaken by researchers working at the North Atlantic Treaty Organization (NATO) Undersea Research Centre (NURC) in Italy and the Faculty of Electrical Engineering and Computing at the University of Zagreb in Croatia, who have tested and evaluated AUVs conducing maritime security tasks, such as NMCM detection and neutralisation.[20] NURC scientists have experimented with Mission Orientated Operating Suite Interval Programming (MOOS-IvP) in their AUVs. This capability fulfills the RCN's requirements for flexibility and reduced risk. For example, MOOS-IvP software architecture provides AUVs with the ability to react dynamically to their environment, thereby increasing functional autonomy.[21] During one trial, output from a sonar sensor directed the robot to change its trajectory while its on-board system developed a new mission in response to this data.[22] Furthermore, NURC has conducted NMCM trials using an Autonomous Surface Vehicle (ASV) in collaboration with AUVs to detect, classify and neutralise mines.[23] The RCN requires this technology to develop its future capabilities since, apart from ASW functionality, an ASV must also be able to perform underwater surveying and engineering."[24] However, NURC researchers have not tested their products in Arctic waters. Further research and development of this technology is therefore required to meet the RCN's requirement to execute maritime security operations in the North.

Working in the Arctic

Canada is an Arctic state and, over the past 20 years, the RCN has been increasingly involved in northern operations. Conducting military and whole-of-government underwater operations in the Canadian High Arctic is difficult under the best circumstances but ASVs offer the promise of new capabilities and efficiencies. Canada's existing capabilities are adequate but not ideal. Surveys from icebreakers are slow and cannot easily navigate thick multi-year ice and helicopters are limited by weather and seasonal restrictions.[25] By their very nature, an ASV would be a desirable asset. Unmanned, with long endurance, they could theoretically replace some of the government's manpower-intensive platforms.

A notable example is the ISE Ltd. Explorer AUV, a system that was deployed under Canadian Arctic ice to perform bathymetric surveys. It had an endurance of hundreds of kilometres (10 days of in-water operation) and collected data towards Canada's United Nations Convention on the Law of the Sea (UNCLOS) claim.[26] While not a defence asset, it offers clear evidence that AUVs can be adapted to under-ice operations. Indeed, Canadian and international researchers have conducted significant research and development on AUVs operating in Arctic conditions. In 2010, industrial scientists and engineers from the University of Tokyo and private industry successfully deployed the first Japanese under-ice AUV in the Okhotsk Sea.[27] Although their tests yielded positive results with respect to coverage and reduced risk to personnel, their prototype does not meet RCN requirements for flexibility and endurance in the Arctic. For example, the Aqua-Explorer 2000a (AE2000a) AUV successfully profiled icebergs using a Multi-Beam Echo Sounder (MBES) capable of upward and downward profiling.[28] However, it failed to meet cold-water requirements. During the underwater ice-floe survey, the AE2000a experienced "cold-induced hardware malfunctions," resulting in a significant drop in voltage, causing it to reboot in the middle of a mission.[29] Furthermore, this prototype is specifically designed for civilian applications. The AE2000a can conduct simultaneous seabed gouging and iceberg profiling in support of oil resource development.[30] Although this capability could be used in Arctic operations to survey the sea bottom for navigational purposes, the AE2000a is not designed to conduct NMCM and other maritime security operations.

In 2010, a researcher from the Escuela Superior Politecnica del Litoral University in Ecuador developed an experimental AUV, referred to as the HIPOPOTAMO III (HIP III), to collect water and sea floor samples near the Ecuadorian Scientific Base Pedro Vicente Maldonado in Antarctica.[31] Notwithstanding the fact that the HIP III is described as being "low cost" and capable of under-ice exploration, it does not fulfill the RCN's requirements for flexibility and robust communications. Like the AE2000a, the HIP III is not intended for military operations. Instead, it is designed for scientific research, specifically to collect samples of the water column, temperature, conductivity, pressure and images of the sea floor in order to estimate the amount of fresh water melting from a nearby glacier.[32] Although some of these capabilities are required in maritime operations – specifically ASW – this prototype is does not offer any new capability with respect to anti-mine warfare. Moreover, the HIP III's communications suite is far too limited for military applications. While operating on the surface for example, it communicates using a fused Global Positioning System (GPS) and Inertial Navigation System (INS).[33] However, while operating underwater, the HIP III only uses the INS.[34] This is problematic from procurement perspective, as the MUS concept document explicitly states that "[s]ole reliance on GPS and/or other Precise Navigation and Timing (PNT) systems creates a single point of failure."[35] This proved to be the case during the HIP III's trials. The Chilean Navy tested this prototype from one of its ships transiting Drake Passage and discovered that it suffered a significant INS error, with no other system to rely upon for redundancy.[36]

Scientists and researchers from DRDC and International Submarine Engineering (ISE), a private industrial firm based out of Port Coquitlam, BC, collaborated on and tested their own AUV – the Explorer – in the Arctic in 2010.[37] Natural Resources Canada (NRCan) required this capability in order to conduct under-ice bathymetric surveys in support of Canada's UNCLOS Outer Continental Shelf claim.[38] This particular AUV does not meet all of the RCN's requirements with respect to flexibility in operations. For example, the Explorer does not have the ability to conduct NMCM operations, nor is it easy to operate from a ship with limited crew. Compared with the AE2000a, that weighs 300 kg with an overall length of 3 m, and the HIP III that weighs almost 52 kg and is just less than 2 m in length, the Explorer weighs over 1,800 kg and is almost 7.5 m in length, making it more difficult to operate from a ship.[39] In addition, this particular AUV required the services of a Remotely Operated Vehicle (ROV) to inspect and reconfigure it between missions, thereby making it less efficient for ship-based operations.[40]

Despite these limitations, however, the Explorer does demonstrate a greater potential for future development in the RCN, than the AE2000a and the HIP III, for the following reasons. First, DRDC has significant experience in researching and developing AUV technology in conjunction with Canadian private industry. In 1996 for instance, DRDC collaborated with ISE in creating the Theseus AUV.[41] This particular model successfully laid 200 km of fibre optic cable out to the edge of the continental shelf under the ice, and returned back to the hole where it was launched for recovery.[42] Since then, both organisations have built upon this technology to create the Explorer. Based on the positive results observed during NRCan's UNCLOS mission in 2010, DRDC and ISE built an AUV that surpassed "all previous known records for continuous operations, distance travelled and operational risk."[43] Secondly, the Explorer is constructed with a robust communication and senor suite, conducive to conducting naval operations in the North. Recognising the limitations of INS in Arctic navigation, DRDC developed long- and short-range homing systems capable of transmitting out to ranges in excess of 100 km under the ice.[44] Finally, the RCN has some experience operating with this type of AUV. In 2014, DRDC scientists and RCN personnel travelled to Victoria Strait to deploy the AUV *Arctic Explorer* in search of the lost Franklin expedition ships.[45] Therefore, it is conceivable that the RCN could work with DRDC to design an AUV capable of conducting specific maritime security operations, such as port survey, NMCM and passive ASW, in the Arctic as well other areas of the world.

Conclusion

In recent years the potential for AUVs to add value to naval operations has grown considerably and research and development efforts have picked up around the world. The RCN has made it clear that it intends to incorporate these systems into the fleet and as a means of providing safer, more cost-effective solutions in mine-hunting, surveillance, and even ASW. This paper has outlined some of the progress being made around the world and how that might be applicable to Canada's unique AUV requirements. A great deal of research has clearly gone into AUV prototypes with military applications, such as NMCM classification and neutralisation, while others have conducted scientific research missions in Arctic-like conditions. Despite this, there does not appear to be an AUV on the market capable of executing naval operations, such as

NMCM and passive ASW, in harsh Arctic conditions – as Canada would require. In order to meet Vice-Admiral Norman's goal of conducting expeditionary and domestic maritime security operations, sovereignty operations in the Arctic, and humanitarian missions in conjunction with other government agencies, the RCN needs to continue its research and development with an eye towards a truly robust and versatile system. This work should be undertaken collaboratively, with the Director General Naval Force Development making the request of DRDC – in conjunction with other research facilities and private industry – to conduct further inquiries into the feasibility of developing and acquiring a collaborative multi-purpose AUV capable of NMCM, passive ASW, Arctic operations, and other maritime security functions, that can be deployed from a ship or an aircraft, in support of both military and whole of government missions.

Cdr Mark O'Donohue joined the Royal Canadian Navy in 1999. In addition to several tours aboard Halifax-class frigates, he served at the Canadian Forces Naval Operation School as the Underwater Training Officer and as the Task Group Weapons Officer for the Commander of the Canadian Fleet Atlantic Staff. He also spent a year at Defence Headquarters as a Project Director in the Halifax Class Modernization Project and is currently with the Maritime Component Commander staff in Halifax, overseeing and supporting ships deployed on named operations.

Notes

[1] Christopher von Alt, "Autonomous Underwater Vehicles," *Autonomous Underwater Lagrangian Platforms and Sensors Workshop*, Vol. 3 (March 2003), 2.
[2] Vice-Admiral Mark Norman, *Commander's Guidance and Direction to the Royal Canadian Navy: Executive Plan 2013 to 2017* (Ottawa: Commander of the Royal Canadian Navy, 2013), 2.
[3] *Ibid*.
[4] *Ibid*.
[5] Director General Naval Force Development, *Concept for Maritime Unmanned Systems (MUS)* (Ottawa: Director General Naval Force Development, November 2015), 1.
[6] *Ibid*., 6.
[7] *Ibid*.
[8] *Ibid*., i.
[9] *Ibid*.
[10] *Ibid*., 8.
[11] *Ibid*., 8-9.
[12] DRDC, "Exercise UNMANNED WARRIOR: an international exercise using autonomous tech to detect underwater mines," 13 December 2016, https://www.canada.ca/en/defence-research-development/news/articles/exercise-unmanned-warrior-an-international-exercise-using-autonomous-tech-to-detect-underwater-mines.html.
[13] Parth Pasnani and Mae L. Seto, "Autonomous Underwater Vehicles – Untapped Operational Capability," *Maritime Engineering Journal*, Vol. 89 (Spring 2019), 9-10.
[14] David Ribas et al, "The Girona 500, A Multipurpose Autonomous Underwater Vehicle," *OCEANS*, IEEE Spain, 2011, 5.
[15] *Ibid*., 1.
[16] *Ibid*.

[17] *Ibid*., 4; Jay Thor Turner, "Model-Driven Development of Subsumption for Multiple Autonomous Underwater Vehicles," Master's Thesis (Kingston: Royal Military College of Canada, 2012).
[18] Director General Naval Force Development, *Concept for Maritime Unmanned Systems*," 4.
[19] *Ibid*., 8.
[20] Vladimir Djapic and Dula Nad, "Using Collaborative Autonomous Vehicles in Mine Countermeasures," *OCEANS*, IEEE Sydney, 2010, 1.
[21] *Ibid*.
[22] *Ibid*., 1, 3-4.
[23] *Ibid*., 3-5.
[24] Director General Naval Force Development, *Concept for Maritime Unmanned Systems*," 7; Director General Naval Force Development, *Concept for Naval Mine Countermeasures (NMCM)* (Ottawa: Director General Naval Force Development, November 2015), 13.
[25] Chris Kaminski et al, "12 Days Under Ice – An Historic AUV Deployment in the Canadian High Arctic," *Autonomous Underwater Vehicles (AUV)*, IEEE Conference, 2010, 1.
[26] DRDC, "Unmanned Warrior."
[27] Kangsoo Kim et al, "Towards AUV-Based Iceberg Profiling and Gouging Survey in Arctic Sea: The First Japanese Under-Ice AUV Deployment in Okhotsk Sea," Underwater Technology Symposium, IEEE International 2013, 1.
[28] *Ibid*., 2.
[29] *Ibid*., 5.
[30] *Ibid*.
[31] A. Cadena, "Development of a Low Cost Autonomous Underwater Vehicle for Antarctic Exploration," *Technologies for Practical Robot Applications*, IEEE Conference, 2011, 76.
[32] *Ibid*.
[33] *Ibid*., 79.
[34] *Ibid*.
[35] Director General Naval Force Development, *Concept for Maritime Unmanned Systems*," 14.
[36] Cadena, "Development of a Low Cost Autonomous Underwater Vehicle," 80.
[37] Kaminski, "12 Days Under Ice," 1.
[38] *Ibid*.
[39] Kim, "Towards AUV-Based Iceberg Profiling," 3; Cadena, "Development of a Low Cost Autonomous Underwater Vehicle," 77; Kaminski, "12 Days Under Ice," 3.
[40] Kaminski, "12 Days Under Ice," 2.
[41] *Ibid*., 1-2.
[42] *Ibid*., 2.
[43] *Ibid*.
[44] *Ibid*., 4.
[45] Defence Research and Development Canada, "Searching Uncharted Arctic Waters for Franklin's Lost Ships," 25 January 2016, http://www.drdc-rddc.gc.ca/en/dynamic-article.page?doc=searching-uncharted-arctic-waters-for-franklin-s-lost-ships/i7kv31xe.