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AUTONOMOUS UNDERWATER VEHICLES: A FUTURE CAPABILITY FOR THE ROYAL CANADIAN NAVY

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AIM

1. In an effort to obtain oceanographic data along precise trajectories, in the late 1950s scientists working at the Applied Physics Laboratory of the University of Washington invented the first Autonomous Underwater Vehicle (AUV).[1] Since that time, research and development of AUVs – in both commercial and military applications – has significantly expanded. The purpose of this service is paper is to provide the Director General of Naval Force Development (DGNFD) with the following: an outline of the prominent technological advances and trends evolving in the development of the AUV, and an analysis relating them to the future capabilities and requirements of the Royal Canadian Navy (RCN). As the RCN does not have any AUVs within its inventory, it is recommended that Defence Research and Development Canada (DRDC) conduct further inquiries into developing and acquiring a collaborative multi-purpose AUV capable of: Naval Mine Countermeasures (NMCM), passive Anti-Submarine Warfare (ASW), and arctic operations, that can be deployed from a ship or an aircraft, in support of both military and whole of government operations.

INTRODUCTION

2. In his *Commander's Guidance and Direction to the Royal Canadian Navy: Executive Plan 2013 - 2017*, Vice-Admiral Mark Norman relates RCN planning implications with specific corresponding strategic and national objectives.[2] In response to the Government of Canada's

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[1] Christopher von Alt, "Autonomous Underwater Vehicles," *Autonomous Underwater Lagrangian Platforms and Sensors Workshop*, vol. 3 (March 2003): 2. Some view the torpedo as the first AUV, however for the purposes of this analysis, weaponised payloads will not be examined.

[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.

(GoC) geopolitical aim of employing the RCN as an instrument of national power in dealing with maritime security at home and abroad, Vice-Admiral Norman states that the RCN "must identify ways to deploy more persistently in regions of strategic interest."[3] Understanding that from a national perspective, the GoC places the Arctic as a high policy priority and also supports Humanitarian Operations and Disaster Relief (HODR) missions, the Commander of the RCN has directed his planners to improve the Navy's capacity to conduct and support security and sovereignty operations in the Arctic as well HODR missions.[4] Following this and other strategic direction, DGNFD staff has created a *Concept for Maritime Unmanned Systems (MUS)*. That document 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 MUS, 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]

3. The MUS 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

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[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.

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 MUS concept document states that force developers need 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] This service paper analyses the various technological advances that have developed in the field of AUVs within the context of these planning factors – with the exception of cost, as detailed financial information is not available – to demonstrate that further research and development is required to meet the RCN's future capabilities and requirements.

DISCUSSION

4. Scientists and engineers from around the world continue to develop and expand upon AUV technology. Researchers from the Department of Computer Engineering at the University of Girona in Spain have developed a multipurpose AUV capable of being reconfigured to conduct different tasks.[12] Despite the fact that this AUV meets some of the requirements for flexibility, it does not satisfy the RCN's requirement for coverage. 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.[13] This particular design

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[9] *Ibid*.

[10] *Ibid*., 8.

[11] *Ibid*., 8-9.

[12] David Ribas *et al*, "The Girona 500, A Multipurpose Autonomous Underwater Vehicle," *OCEANS*, IEEE Spain, 2011: 5.

[13] *Ibid*., 1.

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.[14] 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.[15] This capability coincides with the vision outlined in the MUS document, that: "[f]uture systems may be multi-purpose and be able to provide information to support different needs."[16] However, the *Girona 500* has not been tested in arctic-like conditions, and therefore does not meet the requirement for coverage outlined in the MUS concept document, as having "the potential to extend mission duration and operate in harsher environmental conditions."[17] Nor has it been specifically tested to conduct military missions such as passive ASW and NMCM operations.

5. 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, have tested and evaluated AUVs conducing maritime security tasks, such as NMCM detection and neutralisation.[18] 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 dynamically react to their

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[14] *Ibid.*

[15] *Ibid.*, 4; Jay Thor Turner, "Model-Driven Development of Subsumption for Multiple Autonomous Underwater Vehicles," Master's Essay, Royal Military College of Canada, 2012. This essay provides an overview of the different software architectures being used in AUVs.

[16] Director General Naval Force Development, *Concept for Maritime Unmanned Systems* . . ., 4.

[17] *Ibid.*, 8.

[18] Vladimir Djapic and Dula Nad, "Using Collaborative Autonomous Vehicles in Mine Countermeasures," *OCEANS*, IEEE Sydney, 2010: 1.

environment, thereby increasing functional autonomy.[19] 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.[20] Furthermore, NURC has conducted NMCM trials using an Autonomous Surface Vehicle (ASV) in collaboration with AUVs to detect, classify and neutralise mines.[21] The RCN requires this technology for future capabilities. It is clearly stated in the MUS concept document, that in addition to ASW, underwater surveying and engineering, "the most significant contribution of [AUVs] applies to NMCM operations."[22] However, NURC researchers have not tested their products in arctic-like waters. Further research and development of this technology is required in order to meet the RCN's requirement to execute maritime security operations in the North.

6. Conducting military and whole of government underwater operations in the Canadian High Arctic is limited. Surveys from icebreakers are slow and cannot efficiently navigate through thick multi-year ice, and helicopters are limited by weather and seasonal restrictions.[23] Therefore, there is a requirement for AUVs in the North. Canadian and international researchers have conducted significant research and development on AUVs operating in arctic-like 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.[24] Although

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[19] *Ibid*.

[20] *Ibid*., 1, 3-4.

[21] *Ibid*., 3-5.

[22] 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.

[23] 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.

[24] 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.

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.[25] 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.[26] 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.[27] 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.

7. 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. [28] 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

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[25] *Ibid*., 2.

[26] *Ibid*., 5.

[27] *Ibid*.

[28] A. Cadena, "Development of a Low Cost Autonomous Underwater Vehicle for Antarctic Exploration," *Technologies for Practical Robot Applications,* IEEE Conference, 2011: 76.

estimate the amount of fresh water melting from a nearby glacier.[29] 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).[30] However, while operating underwater, the *HIP III* only uses the INS.[31] This is problematic from a 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."[32] This proved to be the case during the *HIP III*'s trials. The Chilean Navy tested this prototype from one of its ships transiting the Drake Passage and discovered that it suffered a significant INS error, with no other system to rely upon for redundancy.[33]

8. 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.[34] Natural Resources Canada (NRCan) required this capability in order to conduct under-ice bathymetric surveys in support of Canada's United Nations Convention on the Law of the Sea (UNCLOS) Outer Continental Shelf claim.[35] 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,

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[29] *Ibid*.

[30] *Ibid*., 79.

[31] *Ibid*.

[32] Director General Naval Force Development, *Concept for Maritime Unmanned Systems* . . ., 14.

[33] Cadena, "Development of a Low Cost Autonomous Underwater Vehicle . . .," 80.

[34] Kaminski, "12 Days Under Ice . . ., 1.

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 1800 kg and is almost 7.5 m in length, making it more difficult to operate from a ship.[36] 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.[37]

9. 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.[38] 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 its hole for recovery.[39] 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."[40] 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

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[35] *Ibid*.

[36] Kim, "Towards AUV-Based Iceberg Profiling . . ., 3; Cadena, "Development of a Low Cost Autonomous Underwater Vehicle . . .," 77; Kaminski, "12 Days Under Ice . . .," 3.

[37] Kaminski, "12 Days Under Ice . . .," 2.

[38] *Ibid*., 1-2.

[39] *Ibid*., 2.

[40] *Ibid*.

homing systems capable of transmitting out to ranges in excess of 100 km under the ice.[41] Finally, the RCN has some experience operating with this type of AUV. In 2014, DRDC scientists and RCN personnel travelled to the Victoria Strait to deploy the AUV *Arctic Explorer* in search of the lost Franklin expedition ships.[42] 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

10. This service is paper has provided the DGNFD with an outline of the prominent technological advances that have developed in the evolution of the AUV, as well as an analysis relating them to his key areas of concern: coverage, flexibility, and reduced risk. Canadian and international researchers have conducted significant research and development on AUV technology. Some have experimented with AUV prototypes in military applications, such as NMCM classification and neutralisation, while others have conducted scientific research missions in Arctic-like conditions. However, 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. In order to meet Vice-Admiral Norman’s goal of conducting expeditionary and domestic maritime security operations, sovereignty operations in the Arctic, and HODR missions in conjunction with other government agencies, the RCN needs to acquire, integrate and exploit AUVs to enhance existing and future maritime capabilities.

RECOMMENDATION

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[41] *Ibid*., 4.

[42] Defence Research and Development Canada, “Searching Uncharted Arctic Waters for Franklin’s Lost Ships,” last accessed 25 January 2016, http://www.drdc-rddc.gc.ca/en/dynamic-article.page?doc=searching-uncharted-arctic-waters-for-franklin-s-lost-ships/i7kv31xe.

11. There are multiple AUVs available for purchase from private industry, none of which meet all of the RCN’s requirements. Therefore, it is recommended that DGNFD request that DRDC – in conjunction with other research facilities and private industry – 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.

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