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SEA MINES AND NAVAL MINE COUNTERMEASURES: ARE AUTONOMOUS UNDERWATER VEHICLES THE ANSWER, AND IS THE ROYAL CANADIAN NAVY READY FOR THE NEW PARADIGM?

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JCSP 39

Master of Defence Studies

PCEMI 39

Maîtrise en études de la défense

Canada

CANADIAN FORCES COLLEGE – COLLÈGE DES FORCES CANADIENNES
JCSP 39 – PCEMI 39
2012 – 2013

MASTER OF DEFENCE STUDIES - MAITRISE EN ÉTUDES DE LA DÉFENSE

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Word Count: 19 887

Compte de mots: 19 887

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ABSTRACT

In an era where sea mines are less expensive, becoming more sophisticated, and more assessable to rogue nations and non-state actors, the Royal Canadian Navy will be required to search, detect, classify and dispose of these weapons which can have a significant impact on its ability to manoeuvre. When operating in an environment with a credible sea mine threat, this deficiency may prevent the RCN from achieving its primary strategic goal, which is one of Global Deployable Sea Control. Autonomous Underwater Vehicles (AUV) possess the potential to provide the RCN with a cost effective capability to counter the sea mine threat, and at the same time, reduce the risk to its maritime forces and personnel. In acquisition of these unmanned systems, the RCN can take advantage of these emerging technologies by integrating AUVs into the future fleet in order to address future sea mine threats. In arguing that AUVs are the most efficient option to re-introduce a full NMCM capability into the RCN, this paper will conduct a review of the sea mine threat, and a summary of NMCM as a naval warfare discipline. As with any new combat system or operational capability, the acquisition of AUVs into the Navy will undoubtedly come with numerous challenges to overcome. The paper will review some of the potential challenges that relate to personnel and training; technology; interoperability; and legal factors. Finally, by identifying significant key issues, future roles, potential challenges and lessons learned; it is hoped that this paper will assist in any future RCN AUV acquisition, which will enable the RCN to meet its assigned roles in the domestic, continental, and international operating environments.

CHAPTER ONE

INTRODUCTION

Whoever can hold the sea has command of everything.[1]

-Themistocles (524-460 B.C.)

In an era where sea mines are less expensive, becoming more sophisticated and more assessable to rogue nations and non-state actors; the Royal Canadian Navy (RCN) will be required to be able to search, detect, classify and dispose of these weapons which can have a significant impact on its ability to manoeuvre. When operating in an environment with a credible sea mine threat, this deficiency may prevent the RCN from achieving its primary strategic goal, which is one of *Global Deployable Sea Control.*[2] Autonomous Underwater Vehicles (AUV) possess the potential to provide the RCN with a cost effective capability to counter the sea mine threat, and at the same time, reduce the risk to its maritime forces and personnel. In acquisition of these unmanned systems, the RCN can take advantage of these emerging technologies by integrating AUVs into the future fleet in order to address future sea mine threats.

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[1] John Bartlett, *Bartlett's Familiar Quotations, 16th Ed, ed.* Justin Kaplan (Boston: Little Brown, 1992), 62.

[2] Department of National Defence, Horizon 2050: A Strategic Maritime Concept for the Canadian Forces (Ottawa: DND, 2012), 14.

OPERATIONAL VIGNETTES

The RCN's strategic documents: *Leadmark 2020* and *Securing Canada's Ocean Frontiers: Charting the Course from Leadmark*; both define three roles of the RCN as being: military; diplomatic; and constabulary. It is also recognized that in the modern context, the RCN will rarely conduct these three roles in isolation, and that the application and overlap of these three roles describes the central theory of naval strategy, which is referred to as Use of the Seas or Sea Control.[3]

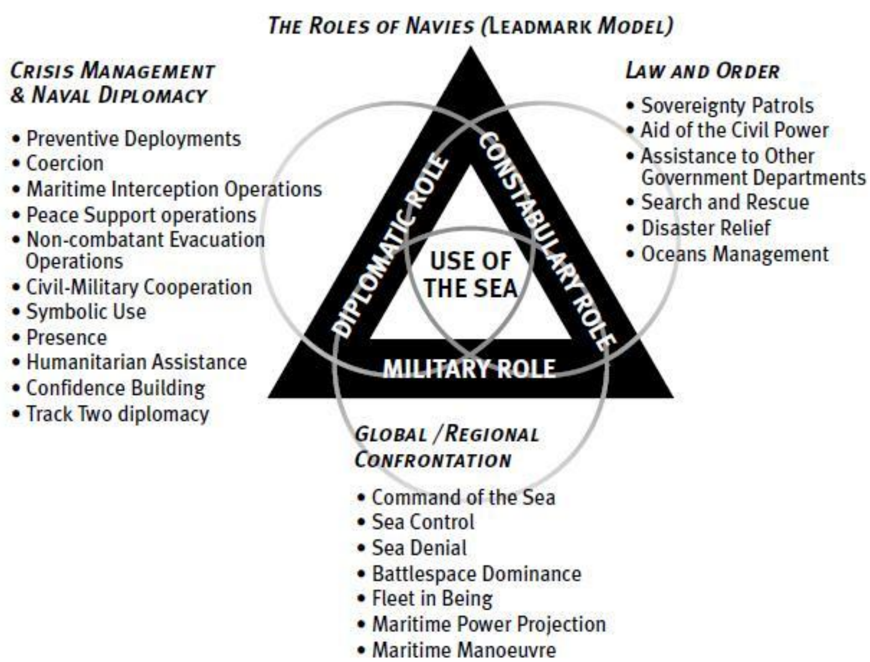

Figure 1 - The Role of the RCN.

Source: Leadmark: The Navy's Strategy for 2020.[4]

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[3] Department of National Defence, Securing Canada's Ocean Frontiers: Charting the Course from Leadmark (Ottawa: DND, 2005), 18.

[4] Department of National Defence, *Leadmark: The Navy's Strategy for 2020* (Ottawa: DND, 2001), 34.

It is within the context of these naval roles that the following vignettes were developed from current and past RCN operations. It should be noted that the insertion of AUVs should not be considered as overly futuristic or even as a new concept; however to the RCN the employment of AUVs will enable a new paradigm in Canadian maritime operations.

Scenario 1

The Canadian Naval Task Group is deployed to the Caribbean, to conduct humanitarian relief operations, as a result of a natural disaster. Due to significant underwater obstructions and damage to the main port facilities, the humanitarian and disaster relief supplies are unable to be disembarked. Naval clearance divers deploy man-portable AUVs from small craft in order to survey the underwater damage. This aids in underwater salvage operations in order to open the port to relief supplies. This contribution earns significant **diplomatic** visibility for Canada.[5]

Scenario 2

The Canadian Armed Forces (CAF) has been tasked to support the Royal Canadian Mounted Police (RCMP) during a major domestic security event in

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[5] Naval Clearance Divers were deployed to the US Gulf Coast as part of Hurricane Katrina relief (OPERATION UNISON 2005), where they conducted underwater search and salvage operations. Department of Nation Defence, "OPERATION UNISON," assessed on 13 January 2013, http://www.cjoc.forces.gc.ca/cont/unison/index-eng.asp.

Vancouver. The RCMP has received a report that a potential Maritime Improvised Explosive Device (MIED)[6] has been laid in the vicinity of Vancouver Harbour. With the port closed to commercial and civilian traffic, the RCN deploys its Naval Mine Countermeasures (NMCM) team. Using a mix of small surface craft equipped with NMCM sonars, Clearance Diving Teams (CDT), and AUVs; the NMCM Commander, is able to conduct an NMCM sequence (Search, Detect, Classify, and Identification) in order to determine that there is no existing underwater threat. As a result of this ***domestic constabulary*** support, the RCMP can re-open the harbour to commercial and civilian traffic.[7]

Scenario 3

During counter-narcotics operations in the Caribbean, it is reported that a suspected drug running vessel jettisoned its cargo prior to a counter-narcotics boarding. A Canadian warship taking part in this ***international constabulary*** operation, and equipped with AUVs, is able to deploy its suite of AUVs to conduct an underwater search mission. The ship is able to find numerous underwater targets of interest, and is able to conduct follow-on identification and recovery operations using a remotely

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[6] Alternatively referred to in the US, as Water Borne Improvised Explosive Devices (WBIED). Christopher Martin, “The Historical Use of Maritime Improvised Explosive Devices,” *Center for Security Studies University of Hull* (August 2010): 2.

[7] NMCM assets from the Canadian Fleet Pacific were involved in the Vancouver Harbour security operations leading up to, and including the Vancouver Winter Olympics (OPERATION PODIUM 2010). Department of Nation Defence, “*Past Operations,”* assessed on 13 January 2013, http://www.cjoc.forces.gc.ca/cont/po-op-eng.asp.

operated vehicle. The embarked AUVs enabled the warship to detect, classify, identify, and recover the jettisoned narcotics, which was then used as evidence by Law Enforcement Agencies to bring the Drug Runners to justice.[8]

Scenario 4

During open hostilities, a Canadian Warship is tasked to provide Force Protection to the NMCM Task Group, conducting NMCM operations in preparation for a coalition amphibious assault. As a self-defence measure, the warship deploys numerous AUVs to conduct mine avoidance, therefore allowing the warship the freedom to manoeuvre in the vicinity of a sea mine threat area, enabling the ship to carry on with its international ***military*** tasking.[9]

INTRODUCTION

Since the end of the Cold War, one naval threat that has remained constant is that of the sea mine. The existence of significant stock piles of legacy sea mines, as

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[8] Canadian Warships are regularly deployed on *Operation Caribbe*. It is the Canadian Forces' recurring participation in the multinational campaign against illegal drug trafficking by trans-national organized crime in the Caribbean basin and the eastern Pacific Ocean. Department of Nation Defence, "*OPERATION CARIBBE," accessed on 13 January 2013, http://www.cjoc.forces.gc.ca/cont/caribbe/index-eng.asp*.

[9] In 2011 during OPERATION MOBILE, HMCS Charlottetown was tasked to conduct Force Protection for the NATO NMCM forces conducting operations off the Libyan port of Misrata. Operation Mobile was the CAF's participation in the NATO Operation Unified Protector. Department of Nation Defence, "OPERATION MOBILE," accessed on 13 January 2013, http://www.cjoc.forces.gc.ca/exp/mobile/index-eng.asp#Task_Force_Charlottetown.

well as the continued global development of a wide variety of modern sea mines presents a significant challenge to naval forces and global maritime security.[10] Sea mines, compared to other conventional naval weapons systems, are less expensive, easier to deploy, and are becoming more accessible to rogue nations, and non-state actors. As a result of this potential sea mine threat, the RCN, whether operating in domestic or international waters, recognizes that it must be ready to deal with this potential threat to its warships and merchant shipping, as well as to guarantee that its strategic sea lines of communication (SLOC), vital shipping routes, commercial seaports and naval bases remain open and uncontested.

The RCN is among the most modern and technologically advanced middle power navies in the world. However, as demonstrated during the 1991 Gulf War, even relatively low cost and basic sea mines can cause significant damage to modern warships, and have a strategic and operational impact on a military campaign. In February 1991, the coalition naval forces lost control of the Northern Persian Gulf, due to significant minefields laid along the Iraqi and Kuwaiti coastlines. The minefields consisted of a mix of more than a thousand bottom influence, moored contact and drifting sea mines. It is interesting to note that it is estimated that twenty percent of the contact mines found drifting in the area of operations were

[10] Royal Canadian Navy, *Concept for Naval Mine Countermeasures (NMCM)* (Ottawa: DGMFD, 11 September 2011), 3.

intentionally set adrift by the Iraqi forces.[11] Although specifically in violation of the 1907 Hague Treaty, these drifting sea mines further complicated NMCM operations and had a significant impact on commercial trade within the Gulf region.[12] Of note, the majority of the moored and floating sea mines used by the Iraqi Navy were LUGM-145 moored contact sea mines, an indigenous sea mine manufactured in Iraq that was based on the World War One Imperial Russian Navy MKB moored contact mine design.

Figure 2 - Iraqi Sea Mines. Iraqi LUGM-145 Moored Contact (left) and Manta Ground Influence (right) sea mines.

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[11] Thomas R. Bernitt and Sam J. Tangredi, "Mine Warfare and Globalization: Low-Tech Warfare in a High-Tech World," in *Globalization and Maritime Power* (Washington: NDU Press, 2002), 393.

[12] Office of the Judge Advocate General, "Hague Convention (VIII) Relative to the Laying of Submarine Automatic Contact Mines – 1907, Article 1(2)," in *Collection of Documents on the Law of Armed Conflict,* 2005 ed., ed. Directorate of Law Training (Ottawa: DND, 2005), 24.

Source: Covert Shores Naval Warfare Blog.[13]

As a result of the Iraqi sea mines, two US Navy (USN) warships were significantly damaged during the Gulf War operations. Consequently, the coalition leadership was forced to abandon the planned amphibious operation due to the significant risk of casualties.[14] Based on this operational and tactical failure, the USN Chief of Naval Operation stated during a post war interview, “Clearly, our ability to conduct effective naval mine countermeasures . . . . will be critical for the success of future naval operations.”[15] Notwithstanding this well-known lesson learned from the first Gulf War, the RCN currently does not possess a complete NMCM capability, which is comprised of the following sequential steps: search, detect, classify, identify and dispose. Presently, the RCN relies on naval clearance divers to conduct the majority of its NMCM tasks. Although highly skilled, the use of these naval divers is restricted by their maximum operating depth and limited clearance rates.[16] NMCM diving is also considered to be one of the more hazardous operations in the RCN. Consequently, when operating in an environment with a credible sea mine threat, this

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[13] Covert Shores Naval Warfare Blog, “Birth, Death, and Rebirth of the Iraqi Navy,” internet assessed 03 February 2010, http://covertshores.blogspot.ca/2010/10/birth-death-and-rebirth-of-iraqi-navy.html.

[14] United States Navy Expeditionary Warfare Directorate, *21st Century US Naval Mine Warfare: Ensuring Global Access and Commerce* (Washington: United States Navy, 2009), 1.

[15] Frank B Kelso, “Building blocks of naval power,” *US Naval Institute Proceedings* vol 118, no.11 (November 1992): 44.

[16] Department of National Defence, RMDS SOR V2.0 C.001334, *Statement of Operational Requirement: Remote Minehunting and Disposal System* (Ottawa: DND, March 2012), 4.

deficiency may prevent the RCN from achieving one of its over-arching strategic goals, which is one of *Global Deployable Sea Control*.[17]

Given the large amount of contemporary research and development (R&D) conducted by the CAF, its allies, academia, and industry regarding the development and employment of Unmanned Aerial Vehicles (UAV) and Unmanned Ground Vehicles (UGV) in military operations, this paper will focus primarily on the aspects of AUVs within the naval environment. It is expected that the employment of AUVs will offer naval commanders extended combat reach and unprecedented access to the underwater environment. They will act as force multipliers in any naval task group by augmenting maritime domain awareness. This access, coupled with advances in command and control frameworks, will expand the naval commander's sphere of influence within the maritime operational environment. This paper will argue that AUVs should be considered as a future capability within the RCN, primarily to re-introduce a cost effective and credible NMCM capability to meet existing and future sea mine threats. Concurrently, the acquisition of these systems should significantly reduce the risk to its naval platforms and personnel. AUVs will be able to conduct these NMCM operations by taking advantage of emerging technologies, including autonomous behaviors. In order to address current and future operational requirements, and due to the flexible and open architectures employed by these systems; the RCN will also have the ability to integrate multiple AUV systems of

[17] Department of National Defence, *Horizon 2050: A Strategic Maritime Concept for the Canadian Forces* (Ottawa: DND, 2012), 14.

various types into a "System of Systems" concept. This paper will identify issues related to acquisition of these AUVs based on existing and future technology, infrastructure, cost and personnel. As well, it will also examine the advantages that unmanned systems can provide to operations in the maritime environment, potential challenges and implications of integrating AUVs into the RCN, and consider prospective future missions that AUVs may be expected to undertake in support of other naval operations. In doing so, a review of available AUVs will be conducted to include: AUV types; history; development; and key technologies. An industry survey will also be presented, in order to present the reader with a reference on the availability, maturity, and cost benefit of AUV systems.

The concept of unmanned vehicles or systems is not a new or novel concept,[18] as UAVs and UGVs have been employed in military operations for over twenty years.[19] Nevertheless, the operational employment of unmanned systems in the naval environment is still a relatively new concept. However, the employment of these systems should not be considered as overly futuristic or even as science fiction, as these systems and capabilities are currently available to the commercial and academic sectors. As the employment of unmanned systems in military operations continues to

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[18] There is much ongoing debate whether to use the term "Unmanned "or "Uninhabited". The non-gender specific term "uninhabited", is often used in lieu of, or interchanged with, "unmanned". Debate regarding which term is more appropriate is semantic. This paper will use the more common term "unmanned", in accordance with the Canadian Defence Terminology Standardization Board, NATO, US DoD, and Jane's Unmanned Systems Yearbooks.

[19] Expeditionary Warfare Division, *Naval Mine Countermeasures Unmanned Undersea Vehicle Roadmap* (Washington: United States Navy, 2011), 4.

increase within the air, land, and maritime domains, they are quickly becoming very significant components to the order of battle of any modern military. This has been evident during recent combat operations in Afghanistan, Pakistan and Iraq, most specifically with UAV and UGV systems. It has been estimated that the use of unmanned systems in these theatres of operation went from near zero in 2003 at the start of Operation Iraqi Freedom, to more than 10,000 unmanned systems by 2008.[20]

These unmanned systems significantly contribute to situational awareness, targeting, drone strikes, and counter improvised explosive device (CIED) operations. Consequently unmanned systems capabilities are also significantly changing the way in which operational commanders and their planning staffs, organize, and execute military operations in any of the warfare domains. Based on this, there are some experts that consider that unmanned systems are revolutionizing 21st century armed conflict, and their use is becoming limitless, as militaries, academia and industry continue to develop innovative methods in which to employ these systems.

With the growing insatiable appetite for advanced capabilities, combined with the desire to reduce the risk to human life and expensive manned military platforms, military commanders continue to demand better improvements to tackle increasingly more complex factors such as time, space, and force. While unmanned systems continue to pay a significant contribution to air and ground combat operations, their

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[20] James Kraska, "The Law of Unmanned Naval Systems in War and Peace," *Journal of Ocean Technology, Subsea Vehicles* 5, no.3 (July-October 2010): 46.

value in the maritime domain has somewhat lagged behind. As a result, many navies around the world are now just recognizing that the capabilities that are intrinsic in these readily available, affordable and open architecture systems are considerable. It is anticipated that these systems will provide new efficiencies to naval commanders with regards to access to the underwater environment; battle-space control; and a reduced dependence on legacy manned systems.[21] Accordingly, many navies have acquired these systems or are commencing acquisition programmes.

In accordance with the *Canada First Defence Strategy (CFDS)*, the RCN is embarking on a period of transformation and fleet revitalization, with the introduction of three new classes of warships into the RCN over the next 10-15 years.[22,23] As part of the capital equipment acquisition process, the RCN will be conducting options analysis and definition activities to support the future designs and capabilities of these new warships. Consequently, the RCN project teams are analysing current and emerging threats against developing novel technologies. As a result of these activities, the RCN has begun evaluating various types of unmanned systems in order to determine their possible naval applications in relation to the RCN's assigned roles.

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[21] Kevin Tokarick, "Employment Considerations in the Use of Undersea Vehicles by the Operational Commander," (Department of Joint Military Operations Department, Naval War College, 2005), 2

[22] The Canada First Defence Strategy highlights that the government will procure Arctic Offshore Patrol Ships; Joint Support Ships; and will replace the current Destroyers and Frigates with single class Surface Combatants. Department of National Defence, *Canada First Defence Strategy* (Ottawa: DND, 2009), 4, 16, 17.

[23] Public Works & Government Service Canada. "National Shipbuilding Procurement Strategy (NSPS)," Assessed 21 January 2013, http://www.tpsgc-pwgsc.gc.ca/app-acq/sam-mps/snacn-nsps-eng.html.

As part of the process of this analysis, the Navy is gathering lessons learned from allied navies, industry and academia; as well as attending allied and industry sponsored tests and trials. All which indicate that current unmanned systems are now entering an age where they are achieving very high Technology Readiness Levels (TRL)[24] and affordability.

In arguing that AUVs are the most efficient option to re-introduce a NMCM capability into the RCN, this paper will conduct a review of the sea mine threat, and a summary of NMCM as a naval warfare discipline. As with any new combat system or operational capability, the acquisition of AUVs into the Navy will undoubtedly come with numerous challenges to overcome. The paper will review some of the potential challenges that relate to personnel and training; technology; interoperability; and legal factors. Finally, by identifying significant key issues, future roles, potential challenges and lessons learned; it is hoped that this paper will assist in any future RCN AUV acquisition, which will enable the RCN to meet its assigned roles in the domestic, continental, and international operating environments.

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[24] TRLs are defined by NATO as the state of an evolving technology. The various TRLs enable the R&D and operational communities to define at which point an evolving technology can transition from R&D to operational and tactical development. NATO Research and Technology Organization, TR-IST-052, *Bridging the Gap in Military Robots: A Report on the Requirements and Gaps in Short Term Military Robotics (Bonn Germany: NATO, September 2004), Annex A.*

CHAPTER TWO

THE THREAT

We have lost command of the sea to a nation without a navy, using weapons that were obsolete in World War I, laid by vessels that were used at the time of the birth of Jesus Christ.[25]

-Admiral A.E. Smith USN, after defeat by sea mines before Wonsan, Korea, 1950

THE SEA MINE AND ITS HISTORY

Sea mines, and more recently Maritime Improvised Explosive Devices (MIED), are established and proven naval weapons. Historically, they have proven to be pervasive, inexpensive, easy to produce, simple to deploy, and yet difficult to counter. They constitute a disproportionate threat to naval forces and civilian shipping, when compared to the cost, effort and skill needed to deploy them. The global threat from sea mines arises from the existence of significant historical stockpiles, the recent proliferation of a wide variety of modern sea mine designs, and most recently the use of MIEDs. Conventional sea mines vary in sophistication, but are readily available, and improvised versions are relatively easy to construct. Generally less expensive than other types of naval weapons, sea mines can inflict

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[25] During the Korean conflict, a large UN naval and amphibious force was prevented from entering the North Korean port of Wonsan, due to the inability to detect and avoid minefields. History was repeated during the first Gulf War, when a large Coalition amphibious force was prevented from conducting a landing on the Kuwaiti coast due to the same inability to detect and avoid Iraqi minefields. Both minefields were laid by rudimentary surface craft, including junks and dhows. Ocean Studies Board, National Research Council, *Oceanography and Mine Warfare* (Washington, DC: National Academy Press, 2000), 12, http://www.nap.edu/openbook.php?record_id=9773&page=12. Internet accessed 12 Jan 2013.

catastrophic damage to shipping and warships, and create huge tactical, operational and strategic uncertainties.[26] Due to these characteristics, sea mine threats continue to frustrate the most powerful of maritime nations and are likely to draw modern naval forces into a disproportionately expensive, time consuming and asset-rich NMCM operation before sea control in the littoral environment can be regained.[27] Sea mines have become especially attractive asymmetric weapons for small naval powers as well as those irregular non-state actors engaged in international crime or terrorism, allowing them to disrupt naval operations, and harass legitimate users of international waterways, port facilities and force the shutdown of merchant shipping.

For a sea mine threat to exist, the following two essential conditions must be fulfilled: first, the possession of the capability (the weapons and training), and second, the political and military will to use the weapons. Sea mines also can inflict remarkable psychological effects on a target population. Consequently, if a nation or non-state actor possesses the above capabilities, in certain circumstances, it may not even be necessary to deploy the actual sea mines. Just the simple claim or stated intent that sea mines or MIEDs have been laid, can also achieve a strategic result by

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[26] "On 18 February 1991, the billion-dollar Aegis cruiser USS Princeton (CG 59) suffered a "mission kill" from an Iraqi-laid Italian Manta multiple-influence bottom mine costing about $25,000; the warship was out of service for the duration of Operation DESERT STORM and longer. Several hours earlier that same day, USS Tripoli (LPH 10) struck an Iraqi moored contact mine, which ripped a twenty-three-foot hole in the hull and came close to sinking the ship." Scott C. Truver, "Taking Mines Seriously: Mine Warfare in China's Near Sea," Naval War College Review 65, no. 2 (Spring 2012): 32.

[27] Littoral areas are defined as the coastal sea areas which are vulnerable to influence or support from the sea, normally accepted as the area which horizontally includes the land-water area from 100 km inland to 200 nm at-sea, and ranging vertically into space to the seabed. Department of National Defence, Leadmark: The Navy's Strategy for 2020 (Ottawa: DND, 2001), 3.

significantly altering the intended conduct of naval operations, as well as inhibiting or reducing the right of passage to a specific SLOC, area of operation or strategic choke-point. Thus, in some situations, a sea mine doesn't even have to sink or damage a ship to have achieved its mission.[28] The sea mine has often been referred to as the "weapon that waits."[29] When compared to other naval weapons, sea mines can be easily stored and concealed in considerable quantities. Additionally, they are relatively inexpensive to acquire, have very long shelf lives, and require very little maintenance. These characteristics make the sea mine an attractive weapon.[30] Currently, it is estimated that there are in excess of 250,000 sea mines within the inventories of at least fifty navies.[31] Market analysis conducted by Jane's Underwater Warfare Systems indicates that there are in excess of thirty nations that produce, and of these nations, more than twenty export sea mines on the international arms market.[32] Probably more alarming is that these international figures do not account for the existence of MIEDs, which can be fabricated from readily available materials, such as: fuel bladders, steel and plastic barrels, and even discarded refrigerators.[33]

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[28] In 1980, the "Patriotic Scuba Divers" declared the mining of the Sacramento River in California, closing the port for 4 days. Scott Truver, "Mines and Underwater in US Ports and Waterways: Context, Threats, Challenges and Solutions," *Naval War College Review* (Winter 2008), 110.

[29] Scott C. Truver, "Taking Mines Seriously: Mine Warfare in China's Near Sea," *Naval War College* Review 65, no. 2 (Spring 2012): 31.

[30] Jane's, *Jane's Underwater Warfare Systems, 2010-2011, ed. Clifford Funnell (Coulsdon: IHS Jane's, 2010), 395.*

[31] Expeditionary Warfare Division, *21st Century US Naval Mine Warfare: Ensuring Global Access and Commerce,* (Washington: United States Navy, 2009), 7.

[32] Scott C. Truver, "Taking Mines Seriously: Mine Warfare in China's Near Sea," *Naval War College Review* 65, no. 2 (Spring 2012): 31.

[33] Christopher Martin, "The Historical Use of Maritime Improvised Explosive Devices," *Hull University Centre for Security Studies IED Project Paper No.1 (August 2010):* 19.

Notwithstanding the potential of sea mines as a naval weapon, historically, there have been relatively few incidents of conventional sea mining in North American and Canadian territorial waters. This can be attributed to the geographic isolation of North America from other regions by the oceanic barriers on both coasts. In fact there have only been three confirmed naval mining incidents in Canadian territorial waters. For instance, the first incident occurred in September 1918; where sea mines were laid by the Imperial German Navy submarine, U-155 off Halifax.[34] The last two were during the Second World War, in May 1942, where at least 34 sea mines were laid by U-Boats off Saint John's, Newfoundland; and in June 1943, where 66 mines were laid by U-Boats off the approaches to Halifax Harbour.[35] In total during the Second World War, German U-boats succeeded in laying approximately 327 sea mines from Halifax to the ports of the US Gulf Coast. This caused several ports along the coast to close for various periods of time, as well as the sinking of eleven merchant ships.

However, in comparison with other theatres of war during the same periods, one can easily comprehend the magnitude of the sea mine threat. For instance, during World War One, the Allied and German navies laid over 223,000 sea mines in European waters, mainly in the English Channel, and the North and Baltic seas. These

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[34] William Johnston, et al., *The Seabound Coast: The Official History of the Royal Canadian Navy, 1867-1939, Volume I* (Toronto: Dundurn Press, 2011), 704-705.

[35] Gilbert Tucker, *The Naval Service of Canada: It's Official History, Volume Two: Activities on Shore During the Second World War* (Ottawa: Kings Printer, 1952), 77.

minefields caused the loss of at least 586 Allied merchant vessels and 57 warships; in addition to approximately 1,047 German merchant vessels and 150 German warships.[36,37] During World War Two, the Allied and German Navies laid over 411,000 sea mines in European waters. In total, it is estimated that over 1,050 German and Italian; and 802 Allied merchant vessels and warships were sunk by sea mines, with countless others having been damaged. In the Pacific theatre, Allied mining is estimated to have destroyed 290 Japanese ships.[38]

Notwithstanding, these historic mining examples, the current sea mine threat assessment for Canada currently remains low.[39] Unfortunately, this threat assessment has led some to disregard this potential risk. However, this does not mean that there is no risk to Canada from a potential sea mine threat. Regardless of the current threat, Canada must be able to defend its SLOCs, "especially in the final maritime approaches to the commercially and strategically important ports along Canada's extensive coastline."[40] Although the direct state-on-state offensive sea mine threat to Canada is assessed as low, emerging global security trends, suggest the potential for irregular and hybrid warfare attacks on Canada from non-state actors and criminal

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[36] J.S. Cowie, *Mines, Minelayers and Minelaying* (Oxford: Oxford University Press, 1951), 86.

[37] R.C. Duncan, *America's use of Mines* (Washington: US Naval Ordnance Laboratory, 1962), 71.

[38] Mine Warfare and Clearance Diving Officers Association, "The Development of Naval Mine Warfare," accessed 11 March 2013, http://www.mcdoa.org.uk/Development_of_Minewarfare.htm.

[39] Royal Canadian Navy, *Concept for Naval Mine Countermeasures (NMCM)* (Ottawa: DGMFD, 11 September 2011), 4.

[40] *Ibid.*, 3.

organizations is anticipated to increase.[41] Additionally, due to the growing commercialization of the international arms market; it is expected that the above organizations will acquire access to inexpensive and sophisticated military capabilities.[42] Consequently, the sea mine and its attributes of cost and ease of use may make these weapons an attractive option for conducting future asymmetric attacks against maritime assets and ports.

The commercial ports of Halifax, Montreal, Vancouver, and Prince Rupert; as well as the Saint Lawrence Seaway, are among some of the busiest in the world.[43] Canada has a strategic reliance upon the unrestricted movement of commercial shipping through these ports in order to sustain its economy. Canada also shares many of its vital waterways with the United States (US) and through its integrated economic and security ties are fully engaged in the common defence of North America. Therefore the political, economic and social impact of just one sinking of a merchantman or warship in continental US/Canadian waters is incalculable. Even a brief interruption to operations in these ports would have a direct impact on Canada's economy.

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[41] Chief of Force Development, *The Future Security Environment 2008-2030: Part 1: Current and Emerging Trends* (Ottawa: DND, 27 January 2009), 79-83.

[42] *Ibid*., 83-85.

[43] As Leadmark, points out, "Nearly three-quarters of Canada's gross domestic product (GDP) is derived from international trade, placing Canada among the major trading nations of the world. The container ports of Vancouver, Halifax and Montreal are linked to their overseas counterparts by the global highways of the oceanic trade routes." If the operation of those ports were to be obstructed even briefly there could be severe political and economic consequences.

Aside from the relatively low sea mine threat in domestic waters, the CAF is regularly tasked in expeditionary roles. These expeditionary missions often require the RCN to operate in areas where there is a credible sea mine threat, or where sea mines from previous conflicts still remain a threat. The RCN has operated in the vicinity of known sea mine threats in such multinational operations as: Korea 1950-53; the Tanker War 1987-88; the first Gulf War 1991; the Adriatic 1990s; Operation Iraqi Freedom 2003; and most recently Libya 2011. The Navy also continues to operate in areas of the world that have been exposed to significant sea mine campaigns in the past. For example, Canadian Warships regularly transit European waters, where over two world wars, more than half a million mines were laid, and although significant efforts have been made to clear them from the seas, it is estimated that only 15 to 30% have been actuated, disposed, or recovered to date.

In a recent consultant report, assessing unexploded ordinance risks for the European offshore industry, it conservatively estimates that based on the above percentages, approximately 443,800 legacy sea mines still exist on the seabed in European waters.[44] Although most of these legacy mines have since become dormant due to sitting on the seabed for 60 to 90 years, they remain a risk, as they occasionally wash ashore by tidal action or are recovered by fishing vessels. As an example, in 2005, a Dutch fishing vessel entangled a legacy sea mine in its nets, and in the process of recovering its catch hauled the sea mine onto its hull. Despite the fact the

[44] PMSS and Alpha Associates, *Unexploded Ordnance Risk: Considering Unexploded Ordnance Risk on and around the British Isles* (Romsey: Broadwater House, 27 April 2011), 10.

sea mine was of World War One or Two vintage, it detonated, killing three and wounding several other crewmembers.[45] As a result of the threat these legacy sea mines pose, Mine Countermeasures Vessels of the North Atlantic Treaty Organization (NATO) Standing Mine Countermeasures Group One (SNMCMG1); regularly operate in the English Channel, North, Kattegat and Baltic Seas, conducting NMCM operations, specifically against legacy World War One and Two era sea mines. As recently as February 2013, while conducting operations off the coast of Holland and Belgium, SNMCMG1 ships located and disposed of eight legacy sea mines over a two week operation.[46]

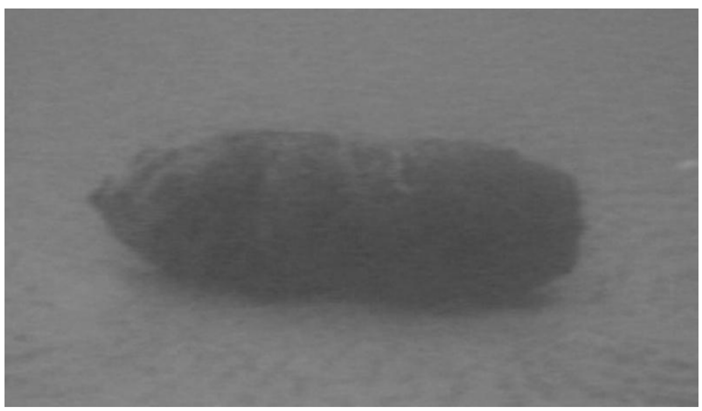

Figure 3 – Legacy Sea Mine. World War Two German Magnetic Ground Mine located by a SNMCMG1 vessel off the approaches to the Belgium port of Zeebrugge, February 2012.

Source: NATO.[47]

[45] NATO, SNMCMG1, "Press Release, Beneficial Cooperation – Two Tons in Two Weeks," accessed on 12 March 2013, http://www.mc.nato.int/PressReleases/Pages/Beneficial-Cooperation-Two-Tons-in-Two-Weeks.aspx.

[46] *Ibid*.,.

[47] NATO. SNMCMG1. "Operation Beneficial Cooperation: Five Days, Five Blasts," accessed on 12 March 2013, http://www.mc.nato.int/PressReleases/Pages/Five-days,%20five-blasts.aspx.

History has demonstrated that sea mines can create havoc for naval forces in the achievement of sea control, as well as potentially disrupt a nation's economy. They have proven to be cost effective, and a pervasive threat, which can be resource intensive to defeat. In fact, as demonstrated by the quantity of legacy sea mines remaining from previous conflicts, sea mines will continue to remain a persistent threat well after a conflict has ended. Given that sea mines will continue to pose a threat to the RCN, it is imperative that it should not only understand the threat and the principles of Mine Warfare, but the Navy should also possess a credible capability to defend itself against sea mines.

SEA MINE TYPES

Sea mines come in many different shapes and sizes, and are classified by their position in the water, as well as their method of actuation. They can be laid from aircraft, warships including specialized minelayers, and "unconventional platforms such as fishing vessels, tugboats, or small pleasure craft."[48] For more covert requirements, many navies can deploy sea mines from submarines.

[48] John Rios, "Naval Mines in the 21st Century: Can NATO Navies Meet the Challenge?" (Master's Thesis, Naval Post Graduate School, 2005), 11.

Figure 4 – Iraqi Minelayer. Iraqi Harbour Workboat converted to carry and lay moored contact sea mines, prior to Operation Iraqi Freedom.

Source: Iraqi Armed Forces Forum.[49]

For example, during the first Gulf War, Iraqi forces initially used its fleet of naval minelaying vessels and Aerospatiale Super Frelon helicopters as its primary minelaying platforms. Although after the coalition established air superiority, they rapidly switched tactics and released the remaining sea mines with a fleet of converted commercial vessels (see fig. 4).

When classified by their position, sea mines fall into the following three categories: moored, bottom, and drifting. The drifting mine has been all but eliminated from the world's inventory in accordance with the Hague Convention of 1907. Notwithstanding, the Hague Convention, drifting mines have been infrequently employed in recent conflicts by third world countries. The second classification method of sea mines is their method of actuation, which can either be described as being contact, influence or remote-actuated.

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[49] Iraqi Armed Forces Forum, "Minesweepers and Minelayers of the Iraqi Navy," accessed on 16 February 2013, http://iraqimilitary.org/forums/viewtopic.php?f=8&t=101

Moored Sea Mines

The design of the moored sea mine has not significantly changed since the early models of the First and Second World Wars. They remain today, relatively unsophisticated, although extremely effective, simple to manufacture and easy to deploy. A moored sea mine comprises of the mine, an anchor, and a mooring cable. The moored sea mine and its associated anchor and mooring cable are laid together as a composite unit by the deployment platform. Once the sea mine reaches the seabed, the sea mine is released from the anchor mechanism, rising on the mooring cable to a pre-set depth. Originally the outer casing of the sea mine was made of steel, although some newer variants are now being manufactured using Glass Reinforced Plastic (GRP) in order to reduce the sonar target strength. Inside the buoyant casing of the sea mine, contains the explosive charge, fuses, detonators, sensors, batteries and security devices.

Figure 5 – Libyan Sea Mine. Moored contact sea mine laid by pro-Qadhafi forces off the Libyan port of Misrata. The picture is from the video feed from an expendable mine disposal vehicle launched from HMS Brocklesby prior to destroying the sea mine. The sea mine can be seen entangled in an inflatable boat which was either sunk to act as camouflage or as a result of the sea mines weight.

Source: Royal Navy (RN).[50]

Moored sea mines are employed at different depths within the water column depending on the target via a mooring cable. Due to the requirement for the sea mine to be buoyant, smaller explosive charges are used in order to allow for buoyancy. The benefit of moored sea mines "is that they may be employed in both shallow and deep water which allows them to be used against a greater variety of targets."[51] The main shortcoming of these sea mines is that they are readily detectable by current NMCM sonars, "since they do not enjoy the concealing properties of burial or seabed

[50] Royal Navy, "Royal Navy Sharing Expertise With US Navy," accessed on 30 March 2013, http://www.royalnavy.mod.uk/News-and-Events/Latest-News/2013/February/19/130219-Royal-Navy-sharing-expertise-with-US-Navy

[51] John Rios, "Naval Mines in the 21st Century: Can NATO Navies Meet the Challenge?" (Master's Thesis, Naval Post Graduate School, 2005), 14.

clutter."[52] Notwithstanding the disadvantages, the moored sea mine still retains its significance for defensive purposes, protecting areas of vulnerable coastline suitable for amphibious landing, important port areas and anchorages and to control shipping movements in choke-points and straits.

The two primary means of sea mine detonation are contact and influence. Contact sea mines are generally moored or drifting, they possess chemical horns or galvanic antennas that trigger actuation after these devices contact the hull of a vessel. Based on their mature designs, contact sea mines are the most economical and less advanced sea mines that are available to developing nations. The influence actuation method will be discussed in the bottom sea mine section.

The more advanced and dangerous variants of the moored sea mine are known as rising or moored influence target-seeking sea mines. These sea mines can be deployed in deep water, and target primarily submarines. These influence sea mines either detach themselves and rise into the path of a target or becomes self-propelled when the targeting criteria are met.[53] These are extremely innovative sea mines that were exclusive to the Soviet Union and the US during the heights of the Cold War, but are now available on the world market or have been developed by other countries. For example, the Chinese EM55 rising sea mine, capable of being deployed to depths

[52] *Ibid.*, 14.

[53] Self-propelled versions of the rising sea mine, basically transforms into a homing torpedo once the mine obtains a firing solution.

of more than 200 meters (m) , has been exported to countries such as North Korea and Iran.[54]

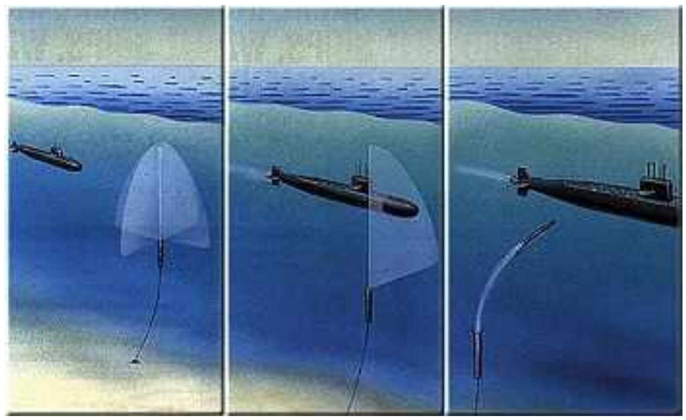

Figure 6 – Rising Sea Mine. An example of a moored rising influence sea mine. In this case, the sea mine is targeting a submerged submarine. The concept is that when the submarine enters into the sea mines detection range, the sea mine's sensors will compute when to engage the target. In this case, the mine is self-propelled.

Source: Russian Naval Weapons.[55]

Bottom Sea Mines

Bottom sea mines rest on the seabed and although they come in many shapes and sizes, the majority of designs are cylinder-shaped in order to make them easily deployable from ships, submarines and aircraft. Outside of improved electronics and signal processing, newer ground mine designs also possess irregular non-cylindrical shapes which are designed to avoid sonar detection, look like natural sea-bed objects, and in some cases aid in self-burial. Ground mines are more challenging to locate

[54] Office of the Chief of Naval Operations, Director Expeditionary Warfare N75, *United States Naval Mine Warfare Plan, Fourth Edition: Programs for the New Millennium* (Washington: Department of the Navy, January 2000) 35.

[55] Stanislav Proshkin, Russian Naval Weapons, "Russian Sea Mines," accessed on 30 March 2013, http://milit.ru/mines.htm.

than moored sea mines. The ability to locate a mine on the seabed is affected primarily by the bottom type (rocky, mud, sand), clutter density (rocks and other debris), and bathymetry. For example, a sandy, non-undulated, uncluttered seabed is more conducive to detecting sea mines on the seabed than a rocky, cluttered (boulders and debris), and rippled seabed.

Figure 7 – Bottom Sea Mines.

Source: Jane's Underwater Warfare Systems.[56]

Whereas a moored contact mine must come into contact with its target, and uses the force of the resulting explosion to cause the damage; a bottom sea mine uses influence signatures that emanate from a passing target vessel, to wake up, track and actuate. The signatures that an influence sea mine can use are: magnetic, acoustic, seismic, pressure, and underwater electric potential.[57] Multi-influence sea mines use a combination of the above signatures to come up with a firing solution, which creates

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[56] Jane's, *Jane's Underwater Warfare Systems 2010-2011, e*dited by Clifford Funnell (Coulsdon: IHS Jane's, 2011), 395-396.

[57] John Rios, "Naval Mines in the 21st Century: Can NATO Navies Meet the Challenge?" (Master's Thesis, Naval Post Graduate School, 2005), 16.

a significant challenge for NMCM systems to be efficiently employed against these sea mines. This NMCM problem is further complicated by the specific sea mine settings, such as selective ship targeting; ship counters; and delayed-arming.[58] Since these mines do not actuate against the ship like a moored contact sea mine, it is not the initial force of the explosion that causes damage or even sinks the ship. Based on distance, the damage is caused as a result of the combination of a superheated, highly compressed gas bubble, along with a shock-wave which carries the explosive energy to the target, subsequently followed by oscillating pressure waves caused by the contraction of the bubble.[59] Based on the necessity for this force to travel through water, bottom sea mines are generally only effective against surface ships in depths between 10 and 90 m.

Remote Actuated Mines

If moored or bottom sea mines are laid in a field close enough to the coast to allow for constant observation, the sea mines can be actuated remotely from a control station or observation post. These types of sea mines are generally employed as part of a systematic and coordinated defense in a coastal area or a choke-point such as the

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[58] A specific targeting setting is used when targeting a specific type of vessel, such as an aircraft carrier or in certain circumstance the Mine Countermeasures vessels. A ship counter is a deliberate setting within the influence sea mine's actuation sequence, where the sea mine will track target vessels, but will not actuate until it reaches it desired ship count. Finally many sea mines can be laid, and remain dormant for a set period of time.

[59] Warren D. Reid, *The Response of Surface Ships to Underwater Explosions* (Melbourne: DSTO Aeronautical and Maritime Research Laboratory, September 1996), 1-3.

Strait of Hormuz. In these areas, sea mines can be employed against naval forces in conjunction with coastal artillery and missile systems. This would be problematic for a NMCM force, who's ships have limited air and missile defence. In this case remote-actuated sea mines play the same role as improvised explosive devices, in that they can be actuated at will, when the Naval Mine Countermeasure Vessels (NMCMV) are in the process of clearing the minefield or a specific vessel of interest is transiting.[60]

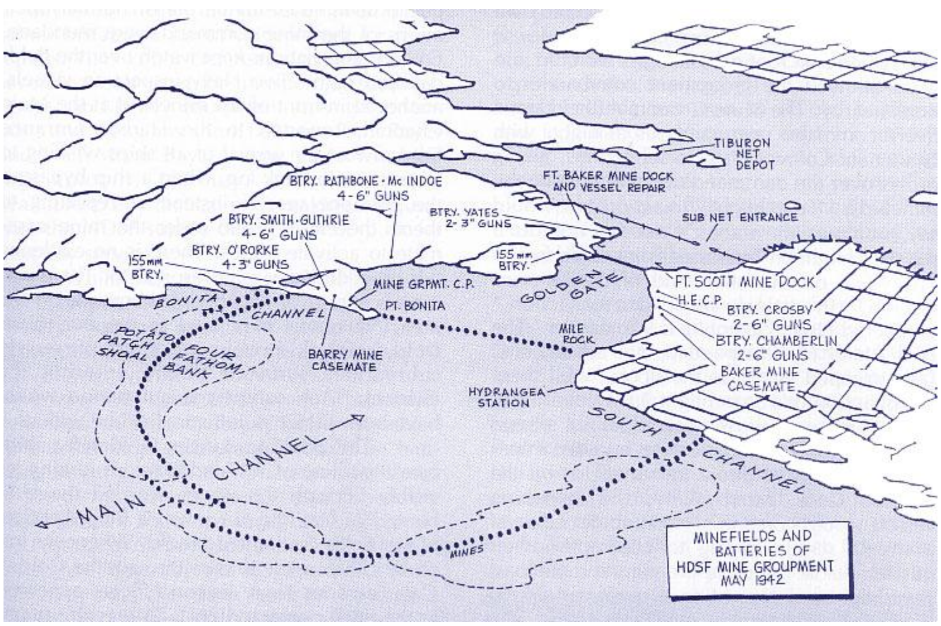

Figure 8 – Layered Defence. Although dated, this World War Two rendition of the networked, layered defence of San Francisco Bay and its approaches, displays an integrated defence of sea mines shore artillery and observation posts. By the end of the war in 1945 the harbor was protected by 481 remote actuated and moored contact mines.

Source: The California State Military Museum.[61]

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[60] Bruce I Gudmundsson, "Covered by Fire: The New Face of Mine Warfare at Sea," *Marine Corps Gazette* 83, no.3 (March, 1999): 33.

[61] California State Military Museum, "Forts Under the Sea Submarine Mine Defense of San Francisco Bay," accessed on 31 March 2013, http://www.militarymuseum.org/Mines.html.

Sea Mine Type Summary

Table 1 - Sea Mine Types and Purpose.

Mine Types	Target/Purpose	Actuation Method[62]	Depth Range	Charge Weight
Shallow Water/Anti-Invasion/Beach Zone	Defence against amphibious landing or beach crossing. Small ships, landing craft, land combat vehicles.	Primarily contact, some influence. Anti-personnel/tank landmines are very effective for this purpose.[63]	0 – 5m, including surf zone	0.1 – 50kg
Ground	Surface ships and submarines. In depths greater than 80m, target primarily submarines only.	Exclusively influence. Some types can be remote actuated from a shore position.	3 - 200m	20 - 1500kg
Drifting mines	Any surface vessel. Creation of random hazard in a coastal area.	Contact[64]	Surface and near surface	5 - 50kg
Shallow moored mines	Surface ships and submarines. Area sea denial, offshore seaward defence barrier or offensive mining.	Type A: Contact is most common form of actuation for mines moored close to sea surface. Can be remote actuated Type B: Influence	Case depth, 1 - 100m, Sinker depth 10 – 300m	Type A: 20 - 250kg Type B: 100 - 250kg
Rising mines/moored influence target-seeking sea mines	Primarily anti-submarine, but also capable against large surface ships. Choke-point interdiction in channels and straits, attrition of	Influence, with target range analysis and possible active acoustic target confirmation, releases a propelled warhead which rises to attack the vessel or a homing propelled warhead.	Case depth 40 – 500m, Sinker depth 50 – 800m.	200-300 kg

[62] The main underwater ship influences are electro-magnetic, acoustic and pressure. More than one signature can form part of the mine actuation algorithm, in which case the mine is termed a combined or multi-influence sea mine.

[63] Landmines can be used in the beach/surf zone to defend against amphibious landing

[64] Drifting mines are moored sea mines that are set adrift without the sinker/anchor

	submarines at bases.			

Source: The History of the Sea Mine and its Continued Importance in Today's Navy [65]

NAVAL MINE WARFARE PRINCIPLES

Naval Mine Warfare (NMW) has become one of the most misunderstood and readily neglected naval missions carried out by any modern navy. NMW is defined as "the strategic, operational and tactical use of sea mines and the countermeasures to defeat them."[66] NMW is a simple concept which is not completely appreciated.[67] Even though sea mines have been in existence for nearly 150 years, it remains a relatively unknown area of naval warfare for individuals in decision making positions. This is due to a lack of understanding of the characteristics or principles of NMW. Where the primary principle is to let or entice an enemy to transit over the sea mine, which lies in wait for its victim, rather than tracking, targeting, then engaging the enemy.

The character of the sea mine has basically remained unchanged since its first early uses. It is a weapon of position, achieving sea denial in the above and underwater domains. Although the actuation ranges have significantly increased due

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[65] Table developed from the following article: Diana Schroeder, *The History of the Sea Mine and its Continued Importance in Today's Navy,* accessed on 16 January 2013, http://www.history.navy.mil/museums/keyport/The_History_of_the_Sea_Mine.pdf.

[66] Expeditionary Warfare Division, 21st Century US Naval Mine Warfare: Ensuring Global Access and Commerce (Washington: United States Navy, 2009), 3.

[67] NMCM are operations that either reduce the risk or end the threat of sea mines. It is a sub-set of Naval Mine Warfare, and will be discussed in detail in the following Chapter.

to advances in sensor technology, where some influence sea mines can now detect vessels out to several kilometers (km), in the end, a target vessel still must enter the actuation radius of the sea mine for it to function. This positional nature gives the sea mine both advantage and disadvantage. The advantage is that once the sea mine is put into position, it becomes a lay and forget weapon, requiring no further action, or skill in order to fulfill its task.[68] It sits in place, either in constant readiness, dormant for a set period of time, or awaiting a specific type of target. It remains on station regardless of weather or environmental conditions, suppressing its fire until the correct parameters are attained. The disadvantage of the sea mine is that once its location on the sea bed or in the water column has been ascertained the area may be avoided and the discovered sea mines cannot normally be retrieved and redeployed.

By employing sea mines, one can achieve maximum effectiveness at minimum cost and risk to own forces. The operational use of sea mines removes from consideration most traditional aspects of naval warfare, for example, ship-on-ship combat and the pursuit or capture of the enemy. Consequently, mine warfare provides adversaries on both sides with the option of not advancing, not moving his men and material by sea or risking severe losses by attempting to do so. Generally, the philosophy on the use of sea mines has changed radically since the beginning of their use. Originally, sea mines were considered by naval purists as not being an ethical

[68] In comparison, a submarine or warship equipped with torpedoes or missiles must still seek out a target, obtain a firing solution and engage the target before making an escape. This requires not only the expensive warship or submarine, but also tactical skill in operation of the vessel, and risk of counterattack and destruction. By contrast, that same submarine or warship equipped with sea mines could lay them and be well clear of the area when the mines go into action.

means of warfare, often referred to as “devilish devices and used only by the un-chivalrous nations."[69] Like submarines, today, sea mines are considered legitimate naval weapons. This change of attitude has encouraged mine designers to improve the weapon by integrating significant technological sophistication, making the modern sea mine a true smart weapon.

The first successful deployment of operational sea mines was conducted by Tsarist Russia in 1854 against the RN during the Crimean War. During this conflict, the Russians laid over 1000 sea mines consisting of gun powder in wooden barrels in the Crimean and Baltic seas. In the end, due to their rudimentary design, the Russian sea mines did not prove to be very effective and only one RN ship, HMS Merlin was damaged.[70] Notwithstanding the effectiveness of these sea mines, the mere fact that the premier power of the day was significantly delayed from entering the coastal waters of a much inferior adversary remains a prime example of the value or the threat of the sea mine. The acceptance of sea mines would continue to grow, with the realization that they can provide disproportionate power of sea denial to countries with limited or non-existent navies. Again this was demonstrated during the American Civil War, where the inferior Confederate Navy inflicted significant losses on the Union Navy by employing sea mines as “its strategic sea denial weapon of

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[69] Gregory K. Hartmann, *Weapons that Wait* (Annapolis: Naval Institute Press, 1979), 36.

[70] Basil Greenhill and Ann Gifford, *The British Assault on Finland 1854-1855: A Forgotten War* (Annapolis: Naval Institute Press, 1988), 309.

choice,"[71] Also during the Russo-Japanese War, the totally inferior Russian Navy used sea mines to inflict significant losses on the Imperial Japanese Navy. In total, Russian sea mines claimed two battleships, four cruisers, two destroyers and one patrol vessel.[72] In 1915, Turkey with a very small navy employed sea mines to close a strategic choke-point and prevent the French and RN from transiting the Dardanelles. On March 18, 1915, in the process of attempting to force the breakthrough of the Dardenelles, the combined allied force lost the following Battleships and Battlecruisers: FS Bouvet, HMS Irresistible, HMS Ocean, and HMS Inflexible.[73] At the end of this day, an inferior naval power using sea mines in combination with coastal artillery, forced a superior naval force to alter its intentions. In the case of the Dardenelles Campaign, the naval campaign was suspended until the infamous landing at Gallipoli on 25 April 1915. In the end, the Allies never transited the straits, until the Turkish forces capitulated.

In all cases above, the sea mine proved to be a valuable weapon in the hands of an inferior maritime power. In the modern context, the RCN will always deploy its ships as its own or as part of an international task group. In both cases, they generally deploy operationally under an international mandate as part of an overall coalition. Invariably, any coalition task group will generally be technologically and numerically superior to any potential maritime adversary. Consequently, based on historical

[71] United States Navy Expeditionary Warfare Directorate, *21st Century US Naval Mine Warfare: Ensuring Global Access and Commerce* (Washington: United States Navy, 2009), 3.

[72] J.S. Cowie, *Mines, Minelayers and Minelaying* (Oxford: Oxford University Press, 1951), 34.

[73] John Winton, *An Illustrated History of the Royal Navy* (London: Salamander Books, 2000), 153.

trends, in future operational deployments, the RCN will continue to be required to understand the sea mine, and be prepared to defend itself against this potential threat from adversary nations or non-state groups conducting irregular warfare.

CHAPTER THREE

NAVAL MINE COUNTERMEASURES (NMCM)

Any Ship can be a Minesweeper . . . . Once!

- Common Mine Warfare Expression[74]

NMCM OPERATIONS

The objective of NMCM is to decrease the risk to ships, submarines and personnel from the threat of sea mines, thus maintaining the freedom of action implicit in a sea control navy. The most effective method of reducing the risk is to locate and avoid the sea mine threat. If avoidance is not possible, actions must be taken to neutralise them. NMCM operations are conducted in times of peace, rising tension and armed conflict. During peace, the main operational focus is in the conduct of Route Survey, in order to build and maintain a database as part of the intelligence preparation of the battle-space (IPB);[75] legacy sea mine detection and disposal; and NMCM operational readiness preparations.[76] These peacetime activities ensure that NMCM forces are prepared for the potential of irregular or regular mining attacks,

[74] Non-attributable.

[75] The ability to understand the underwater battle-space prior to an engagement is critical to an ASW or NMCM commander. Route Survey is a key peacetime operation which builds the understanding and knowledge of the NMCM battle-space. The RCN is responsible for the Route Survey of Canada's key ports and strategic waterways. This process can be considered as part of the Joint Intelligence Preparation of the battle-space process, as defined in the CAF's Joint Doctrine Manual, *Joint Intelligence Doctrine.* National Defence, *Joint Intelligence Doctrine (Ottawa: DND, 2003),* 1-4.

[76] Operational readiness preparations, refers to ongoing training, maintenance of current NMCM systems, as well as tactical and doctrinal development.

particularly in domestic waters. A positive second order effect of possessing an effective NMCM capability is in the peacetime utility of being able to conduct seabed intervention tasks at the direction of the Government of Canada. [77]

In periods of heightened tension or armed conflict, Canadian doctrine states that NMCM will be vital to defending our sovereign territorial waters, predominantly in terms of preserving free movement of naval and commercial vessels into our ports and waterways, or re-establishing confidence, in order to re-commence the movement of shipping after an attack. In the expeditionary context, doctrine also states that Canadian NMCM must be capable of providing protection to deployed naval forces, in order to allow operations in the littorals and in support of forces ashore.[78] Naval Mine Warfare divided into the two disciplines of Naval Mining and NMCM.[79] Specifically NMCM is subdivided into offensive and defensive components. Offensive NMCM is a proactive measure to eliminate an enemy's sea mine laying capability prior to them undertaking any hostile action. Examples of offensive NMCM are: striking an opponent's sea mine depots; or by destroying its mine laying

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[77] Seabed intervention includes the survey and monitoring of the sovereign seabed; including the inspection and maintenance of underwater installations, structures, cables and pipelines. As such it is not defined in either national military or NATO doctrinal publications, but is being loosely used by the Navy to cover broader underwater operations outside traditional warfare operations, such as underwater search and recovery of aircraft, vessels, and objects of interest and human remains. Swissair Flight #111 near Peggy's Cove in 1998 is an example.

[78] Royal Canadian Navy, *Concept for Naval Mine Countermeasures (NMCM) (Ottawa: RCN, 2011), 5-6.*

[79] Based on political directions, the RCN does not conduct Naval Mining operations, nor does it maintain an operational sea mine inventory. It does maintain a number of sea mine shapes for fleet and NMCM training. A number of these training shapes are instrumented with influence sensors to provide more realistic training.

capability. Defensive NMCM is focussed on the conduct of operations to counter suspected or actual sea mines. Defensive NMCM is further sub-divided into Route Survey, Passive and Active NMCM.

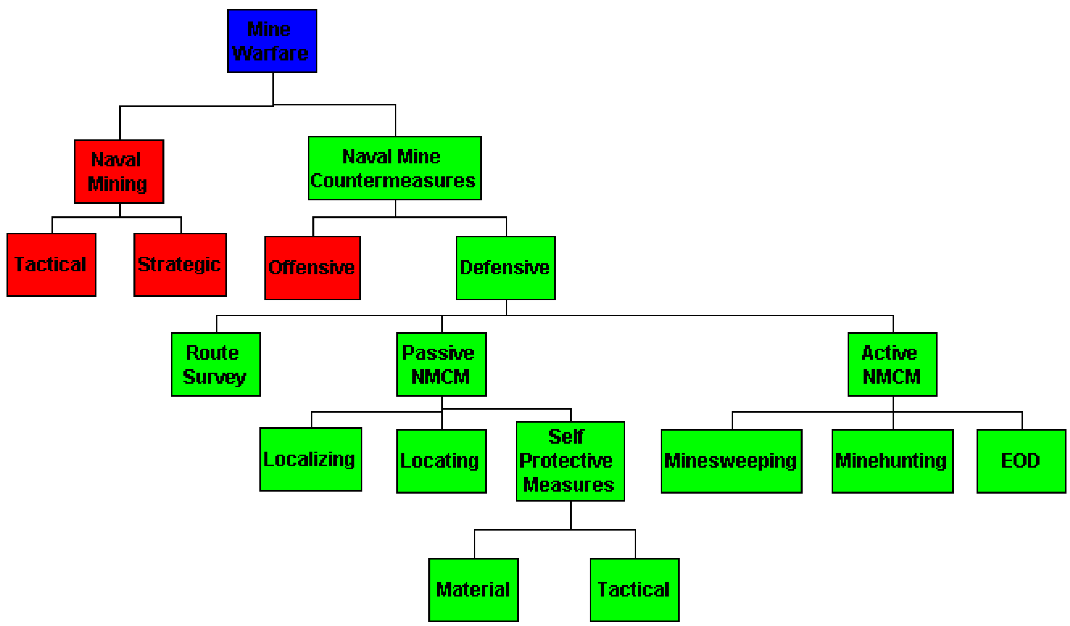

Figure 9 – Naval Mine Warfare Family Tree.

Source: RCN.[80]

Route Survey

Route Survey is the process of surveying using high resolution multi-beam sonars, to classify objects on the seabed along strategic waterways, harbours and their approaches. This NMCM operation is generally conducted in peacetime or during

[80] Royal Canadian Navy, *Naval Mine Countermeasures (NMCM) Concept (Ottawa: DGMFD, 2011), 7.*

periods of low threat during a conflict, and is considered a battle-space shaping technique. The general concept is to survey the areas of interest in order to understand the make-up of the seabed prior to a sea mine being laid. If a new seabed object is detected in a subsequent survey, the next step in the process is to determine the nature of the object, with the goal of classifying it as either a non-mine like or a mine like object. This process is referred to as Change-Detection. If evidence subsequently suggests a hostile mining operation, NMCM operations will transition into active NMCM clearance operations.

Active NMCM

Active NMCM are those activities most often associated with traditional NMCM operations. Currently conducted from very specialized and single purpose NMCM vessels, often constructed of wood, GRP, or very expensive non-magnetic stainless steel. Active NMCM techniques involve the operation of advanced sensors, such as: NMCM sonars, which can be towed, hull-mounted, or variable depth; acoustic and magnetic influence devices used to simulate target signatures; towing of wire sweeps to cut moored mines; and the deployment of neutralisation systems. Other methods also include using helicopters capable of towing the above sensors. The USN also uses specially trained marine mammals, such as dolphins and sea lions to conduct certain NMCM tasks.[81]

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[81] The USN employs several Marine Mammal Systems, such as trained bottlenose dolphins and sea lions for NMCM, swimmer defense, and recovery of mines, torpedoes, and other objects. Each "mammal

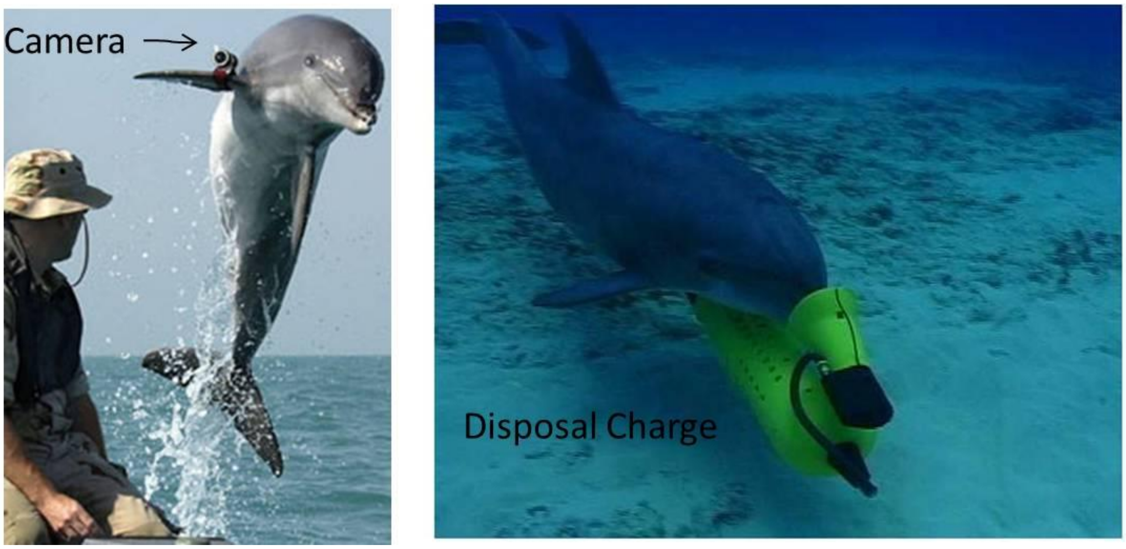

Figure 10 – USN Marine Mammals. The dolphin on the left is equipped for search, detect, and with the camera can bring back images to its handler. The dolphin on the right is about to place a sea mine disposal charge near a suspected mine. In this case, prior to detonating the charge, the dolphin is recovered from the water and the charge is command detonated using an acoustic transponder.

Source: US Navy.[82]

The aim of active NMCM is to conduct the search, detect, classify, identification and dispose sequence. Active NMCM is sub-divided into the following three types of operations: minehunting; minesweeping, and clearance diving.

Minehunting Operations

system" has several mammals that can be rapidly deployed globally. They generally operate in small teams with their handlers in forward operating areas. The mammal systems include:

Mk 4 Mod 0 Dolphins – seabed NMCM;

Mk 5 Mod 1 Sea Lions – object recovery and NMCM in water depths greater than 500 feet; and

Mk 6 Mod 1 Dolphins – security against combat swimmers and divers.

[82] Expeditionary Warfare Division, *21st Century US Naval Mine Warfare: Ensuring Global Access and Commerce* (Washington: United States Navy, 2009), 18.

Minehunting operations are sub-divided into two phases. The first phase comprises of the search, detection and classification of sea mines or mine-like objects. During the first phase, hull mounted or variable depth NMCM sonars are used. In ideal conditions, NMCM sonar clearance rates can approach 100%, but their performance can be affected by environmental conditions, such as depth, turbidity, bottom topography, and seabed clutter. The second phase is conducted to identify seabed objects classified as mine-like; if an object is identified as a sea mine; the phase is completed with the neutralization of the sea mine. This phase is conducted using a Clearance Diver or an identification/disposal vehicle.[83]

Minesweeping Operations

Minesweeping is conducted by the towing of devices, which either physically disable the sea mines or simulate ship signatures to induce the sea mines to actuate harmlessly. Mechanical sweeping is effective against moored sea mines. Influence sweeping can be effective against all influence sea mines, either bottom or moored. Minesweeping is conducted from NMCM vessels, or specially configured helicopters.

[83] Identification/disposal vehicles will be further discussed in Chapter Five.

Figure 11 – Air NMCM. USN MH-53 Sea Stallion NMCM Helicopter, towing a MK105 Magnetic/Acoustic Influence Sled.

Source: US Navy.

Clearance Diving

This highly specialized form of military diving specifically developed to allow close approach to sea mines. It is currently the most effective method of minehunting in confined waters where other methods of active NMCM are not feasible. Clearance divers are able to conduct operations to maximum depths between 60 and 80 m. Clearance diving is also the only method currently available for recovery of mines for exploitation and intelligence purposes.

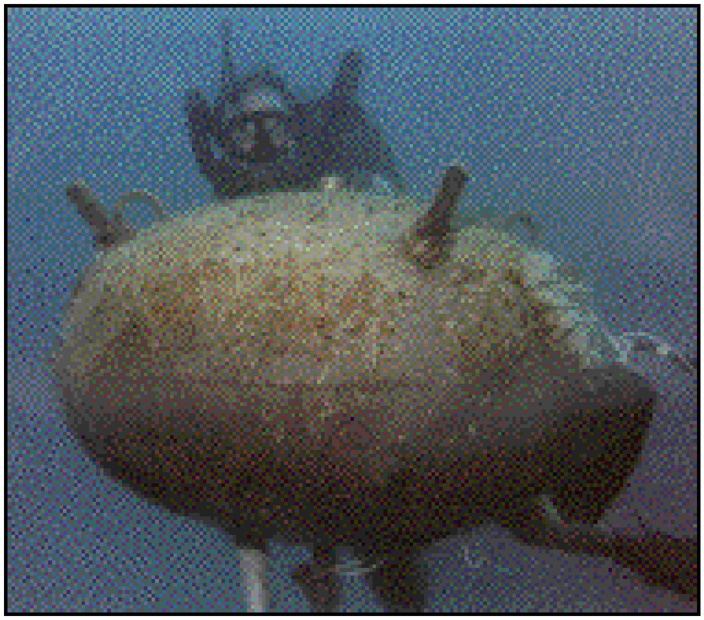

Figure 12 – Clearance Diving. A Clearance Diver prepares a neutralization charge on a moored contact sea mine.

Source: Special Forces.Com.[84]

Passive NMCM

Passive methods used to reduce the risk and localise a sea mine threat include: establishing safe routes, instituting diversions, closing ports, mandating Naval Coordination and Guidance of Shipping, and providing navigational warnings through the Allied Worldwide Navigation Information System (AWNIS).[85]

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[84] Special Forces.Com, "Australian Special Operations Forces Clearance Diving Teams," accessed 07 April 2013, http://www.specialoperations.com/Foreign/Australia/CDT/.

[85] "AWNIS delivers, to military commanders and the merchant marine, assurance against the additional risks to Safety and Security of Navigation that are associated with maritime operations. It is responsible for both classified and unclassified safety and security of navigation information. Outside its applicability for NMCM, AWNIS has been extensively used in the Global fight on Piracy." UK Hydrographic Office, "Fleet AWNIS Unit," accessed 07 April 2013, http://www.ukho.gov.uk/Defence/AWNIS/Pages/Home.aspx.

Techniques to localise a suspected sea mine fields can include surveillance, coastal mine-watches, intelligence, and reconnaissance.

Self-Protective Measures (SPM)

SPMs are measures taken by individual ships for their own risk reduction. SPMs are sub-divided into two areas. The first is Tactical SPMs which can be conducted by any vessel, and include measures such as: reduction of speed, reduced helm control, transiting at high tides, shock-combing, and personnel considerations.[86] The second is Material SPMs, which is either included as part of the vessels design or can be added as a retrofit. Material SPMs can include measures such as: better ship and hull design, including shock-hardening; automatic signature management systems to reduce acoustic, electromagnetic, and seismic signatures; and mine avoidance systems.

THE NMCM CHALLENGE

Unfortunately this chapter's epigraph, which is well known within the NMW community, continues to remain valid. As demonstrated earlier, the sea mine

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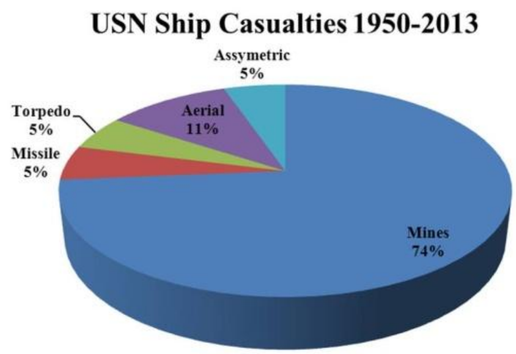
[86] When conducting transits through sea mine danger areas, naval ships can institute personnel SPMs such as: reducing or restricting access to spaces below the waterline; the wearing of Helmets and flash gear; and the posting of sea mine look outs.

continues to remain a significant threat to shipping, as well as to very expensive major naval combatants.



USN Sea Mine Casualties

Korea	Vietnam	Tanker Escort Iran-Iraq War	Gulf War One
USS Barton (DD) USS Mansfield (DD) USS Walke (DD) USS E.G. Small (DD) USS BRUSH (DD) USS Sarsi (ATF) USS Partridge (AMS) USS Pledge (AMS) USS Pirate (AMS) USS Magpie (AMS)	USS Westchester (LST)	USS S.B. Roberts (FFG)	USS Princeton (CG) USS Tripoli (LPH)

Figure 13 – USN Sea Mine Casualties.

Source: USN.[87]

To put the sea mine threat into a quantitative perspective, Figure 13, shows that since the Korean War, the sea mine has been the predominant naval weapon that has damaged or sunk more USN ships than any other naval weapons system. In addition, Figure 14 displays a simple cost comparison of the last three sea mine incidents: the USS Samuel B Roberts in 1988; and the USS Princeton and USS Tripoli both in

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[87] Expeditionary Warfare Division, 21st Century US Naval Mine Warfare: Ensuring Global Access and Commerce (Washington: United States Navy, 2009), 8.

1991; which demonstrates that the cost of the damage inflicted on the vessels far exceeded the actual cost of the sea mine.[88]

Figure 14 – Repair Cost versus Sea Mine Cost.

Source: US Naval Mine Warfare Strategy: Analysis of the Way Ahead.[89]

Since its introduction into naval warfare, the sea mine has developed beyond that of a mere tactical weapon of limited use and importance, and has become a force multiplier capable of influencing the battle-space at the operational and strategic levels. Unfortunately, the historic trends in many navies, including the RCN, have been to ignore this proven weapon. Even after the sea mining incidents described

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[88] Notwithstanding the fact that in all three cases the ships did not sink, the effects of the sea mine strikes ensured mission kills for the three ships that required significant skill and resources to not only save the ships, but to repair them as well. It has been discussed in many forums, that in the case of the Samuel B. Roberts, that the damage was so extensive that most navies would have decided to not to repair the ship.

[89] Gregory Cornish, "US Naval Mine Warfare Strategy: Analysis of the Way Ahead," (US Army War College Strategy Research Project, 2003), 9.

earlier, combined with the fact that many smaller regional navies have acquired sea mines, most navies today, find themselves not fully prepared to deal with a sea mine threat. This state of affairs can be in part attributed to what Naval Analyst, H. Dwight Lyons, refers to as the *Vicious NMCM Cycle,* which is displayed in Figure 15. In his report entitled, *The Mine Threat: Show Stoppers or Speed Bumps*, he specifically describes the relative lack of emphasis that the USN had placed on NMCM prior to the commencement of the first Gulf War, where the USS Princeton and USS Tripoli were struck and significantly damage by sea mines. He then goes on to state that the "navy must break this vicious cycle of ignoring or forgetting past lessons learned, and finally realize the operational importance of mine warfare."[90]

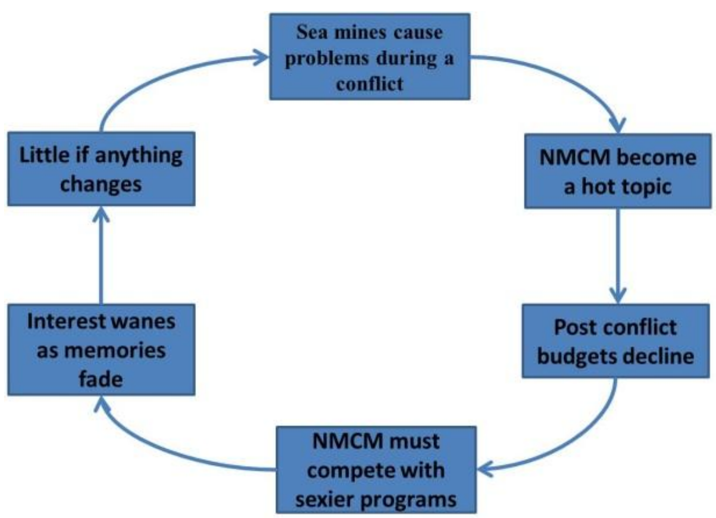

Figure 15 - The Vicious NMCM Cycle.

Source: Center for Naval Analyses.[91]

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[90] Lyons Jr., H. Dwight, et al., *The Mine Threat: Show Stoppers or Speed Bumps?* (Alexandria, VA: Center for Naval Analyses, 1993), 28.

[91] *Ibid*., 28.

In addition, Captain Gregory Cornish USN builds onto the cycle by stating that "the lack of vision, inconsistent unity of effort, minimal readiness and budgetary pressures has plagued the USN NMW community from the Civil War through the Gulf Wars."[92]

The *Vicious NMCM* Cycle, described in Figure 15, is a state of affairs that is common to most western navies. In the context of the RCN, it has been in this V*icious Cycle* since the 1960's, when it relegated its last dedicated minesweepers to navigation and officer training roles. This decision was made so that the Navy could concentrate on the main threat at the time, which were Russian nuclear submarines operating in the deep ocean, and therefore be able to better maintain its Anti-Submarine Warfare (ASW) capabilities. The RCN also became complacent with this decision, with the misguided idea that the USN and plenty of European nations were capable of conducting NMCM if required. Although supported by our US allies and NATO partners, the decision would prove to be short-sighted, for the 1987 Defence White Paper, directed that the CAF would re-introduce a NMCM capability back into the Navy. In order to achieve this, the Navy would be required to re-introduce this naval warfare capability almost totally from scratch. The White Papers of 1987 and 1994 also assigned the NMCM role to the Naval Reserve in order to augment the RCN's current Clearance Diver capability, by operating the Kingston Class patrol

[92] Gregory Cornish, "US Naval Mine Warfare Strategy: Analysis of the Way Ahead," (US Army War College Strategy Research Project, 2003), 14.

vessels with removable NMCM systems.[93] This significant step forward was quickly followed by the Navy's force development document, *Mine Warfare Blue Print 2010*, which laid out the Navy's intentions and way ahead for NMCM. Specifically the Blue Print stated that:

> The Canadian NMCM capability will be credible in countering the mines most likely to be laid in littoral waters, but limited in the amount of equipment and personnel provided. NMCM equipment will be designed to be transportable between platforms, whenever possible. NMCM personnel shall be provided under the Total Force concept and be of modest numbers, but capable of expansion to a larger size in the future, if necessary.[94]

With government and strategic direction in hand, the Navy's force development, operational requirements, and engineering staffs now had the required tools to commence re-building the Navy's NMCM capability. Notwithstanding the direction given, the emerging NMCM capabilities quickly became prey to the *Vicious NMCM Cycle*, as described in Figure 15. Specifically the Navy's NMCM programmes were affected by budgetary constraints of the 1990s and early 2000 period, at the same time as competing against more traditional RCN warfare capabilities and requirements. Consequently the original NMCM systems delivered with the Kingston Class ships were either put into extended readiness, or have since become non-operational due to technical obsolescence and a lack of spare parts.

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[93] The 12 Maritime Coastal Defence Vessels (MCDV), currently known as the KINGSTON Class, were capable initial capable of Mechanical Minesweeping, Route Survey, and Bottom Object Inspection. The ships were designed to embark various NMCM payloads and could change roles within 12 hours. The ships and NMCM payloads were delivered 1996-99.

[94] Chief of the Maritime Staff, Mine Warfare Blue Print 2010 (Ottawa: DGMFD, 1996), 17.

Today, there are many reassuring indications that Defence officials in many countries are putting a much greater emphasis on the NMCM problem, which may lead to finally breaking this cycle of neglect. This has come as a result of an acknowledgement of the sea mine threat, including the potential for asymmetric attacks; and the challenges associated with defeating them. This realization is also balanced by reducing defence budgets, and the risk and cost of having a sea mine damage or sink a major naval combatant. Notwithstanding these initiatives, many nations realize that current NMCM vessels are very expensive, primarily due to the requirement to have very low magnetic signatures and be acoustically quiet.[95] These design criteria, restrict NMCM vessels to the conduct of NMCM and have little operational utility outside this role. In addition they lack speed, which affects their ability to deploy; and do not possess significant self-defence or combat capability. Based on these deficiencies and in an effort to be more cost effective, many navies are intending to rectify these deficiencies by designing multi-role vessels,[96] airborne platforms, as well as providing major combatants with organic NMCM or sea mine avoidance capabilities. It is anticipated that these transformational approaches will rely heavily on future unmanned systems.

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[95] NMCMVs due to their optimised low magnetic and acoustic signatures; unique design and construction; and sophisticated minehunting systems are very expensive and are often quoted as being the world's most expensive surface warship per tonne. Royal Canadian Navy, Naval Mine Countermeasure Concept (NMCM) (Ottawa: DGMFD, 2011), 7.

[96] For example, the USN is intending that the Littoral Combat Ship (LCS) will be its future surface NMCM platform by embarking deployable NMCM payload systems. The LCS will also be able to embark surface, ASW, and SOF payload systems. The RN and the Royal Australian Navy (RAN) are both planning to combine its NMCMV, Patrol, and Hydrographic ship classes into one multi-role platform.

In a similar fashion as its allies, the RCN has also renewed its interest in acquiring further NMCM capabilities. This can be demonstrated by the recent acquisition of new Remotely Operated Vehicles (ROV) [97] and hand held sonars for the CDTs. In addition, it is expecting new Route Survey Systems to be delivered in 2013-2014, to replace the non-operational Kingston Class systems.[98] Operational upgrades to the KINGSTON Class ships are also underway to include installation of advanced new NMCM Command and Control, Degaussing and Dynamic Positioning (DP) Systems.[99] The last planned capability enhancement is the acquisition of a Remote Mine Hunting and Disposal System (RMDS), where the program is in the Definition Phase.[100] The stated objective of the RMDS project is to:

> Acquire an operational unmanned NMCM capability to search, detect, classify, identify, and dispose of modern sea mines or MIEDs that have been laid in waters for which the RCN forces are responsible or operating within.[101]

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[97] These ROVs are discussed in further detail in Chapter Four.

[98] Department of National Defence, "News Release - Route Survey System Life Extension, dated November 2, 2012," accessed 06 April 2013, http://www.forces.gc.ca/site/news-nouvelles/news-nouvelles-eng.asp?id=4482.

[99] Degaussing systems minimise the induced magnetic signature in a ship. It is considered one of the key self-protective measures against influence sea mines. DP Systems can automatically manage the ships propulsion and helm controls to allow for a vessel to hover in a static position. DP systems are critical when operating off-board system such as ROVs.

[100] In accordance with the DND Capital procurement process, the Definition Phase includes obtaining substantive costs, defining levels of risk, and refining the Statement of Requirement.

[101] Royal Canadian Navy, *RMDS SOR V2.0 C.001334. Statement of Operational Requirement: Remote Minehunting and Disposal System* (Ottawa: RCN, March 2012), 1.

Along with dedicated NMCM enhancements to the KINGSTON Class ships, project staffs for the future ship programmes are investigating potential operational requirements for inherent NMCM self-protective measures and organic NMCM capabilities for future fleet combatants.

Just as significant as the current acquisition of new NMCM systems and operational capability, another significant milestone for current and future NMCM development was the promulgation of the RCN's *Concept for Naval Mine Countermeasures (NMCM)*. As a direct replacement for the Mine Warfare Blue Print, the NMCM concept document is intended to give the operational and strategic "intent and direction for naval staffs engaged in developing and sustaining a credible NMCM capability."[102] This direction will enable informed decisions to be made regarding priorities for NMCM R&D, equipment acquisition, tactical development, employment, training and personnel. Notwithstanding, the significant progress and level of effort that is being made to rectify the RCN's NMCM capability deficiencies, this optimism should be tempered with the fact that the Canadian government is in the midst of a deficit reduction programme, where it is expected that the defence budget will come under pressure. This is also occurring at the same time as the RCN embarks on a major fleet renewal programme. Consequently it should be expected that the NMCM programme will be affected, but only time will tell, if the *Vicious NMCM* Cycle will resume.

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[102] Royal Canadian Navy, *Concept for Naval Mine Countermeasures (NMCM)* (Ottawa: DGMFD, 11 September 2011), 1.

CHAPTER FOUR

UNMANNED SYSTEMS

> *During our operation in Libya, the United States deployed critical assets, such as drones. We need such assets to be available more widely among Allies. Delivering unmanned systems is critical, if the Alliance is to respond effectively to the challenges of the future. In fact Unmanned Systems have been identified at the 2010 Lisbon Summit as one of the 11 most critical Alliance capability requirements.*[103]
>
> Anders Fogh Rasmussen, NATO Secretary General

Prior to conducting any cogent discussion regarding the future of AUVs or their potential value in naval operations for the RCN, it must be understood that AUVs fall within the larger family of *Unmanned Systems*. It also must be determined what is meant by *Unmanned*. After reviewing existing military doctrine and published literature, it is obvious that there is no clear cut consensus within the military, industrial, and academic sectors on the term "Unmanned". There is also no shortage of doctrinal and theoretical development of these emerging systems. This can be demonstrated by the development of a new unmanned systems lexicon, with terms such as: *drones, robots, remotely operated, unmanned, uninhabited, piloted, human-in-the-loop, autonomous, semi-autonomous, pilotless, missiles,* and *torpedoes.* The actual term used is often dictated by the given situation, the environment, user sector, intended function, or the level of autonomy. Selecting the right terminology will become more important as unmanned systems become more prevalent in the land,

[103] NATO International Secretariat, 066 STC 12 E, *Unmanned Aerial Vehicles: Opportunities and Challenges for the Alliance* (Brussels: NATO, 02 April 2012), 1.

maritime, and air environmental domains. In order to avoid further confusion and mislead expectations, various organizations such as: NATO, the US Department of Defense (DoD), and the Association of Unmanned Vehicle Systems International (AUVSI)[104] have all established working groups to define the standards for unmanned system taxonomy. For example, simply referring to AUVs or an Autonomous Aerial Vehicle could include systems such as torpedoes and missiles. By establishing a formal taxonomy, this confusion will be avoided, as the design intent for most unmanned systems is to return safely to its host platform.

Although once dismissed as novel and emerging technologies, which would never be useful within a dynamic and complex military environment. Today, unmanned systems have continued to rapidly mature; increase in technical readiness; and arrive in greater numbers. This rapid development has been primarily driven by the desire to provide commanders with greater situational awareness, and to reduce the risk within the 21st century battle-space. Unmanned systems are now providing operational commanders with unprecedented access to real-time Intelligence, Surveillance, and Reconnaissance (ISR) capabilities, along with an emerging ability to strike heavily defended targets.[105] Military unmanned systems can be divided into

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[104] AUVSI is an unmanned systems non-profit organization devoted exclusively to advancing the unmanned systems and robotics community, as well as developing best practices. The community includes industry and academic sector members, as well as military associates. AUVSI, *AUVSI Website,* assessed on 06 February 2013, http://www.auvsi.org/Home.

[105] NATO Research and Technology Organization, RTO-TR-HFM-078, *Unmanned Military Vehicles – Human Factors of Augmenting the Force* (Brussels: NATO, 2007), 4-1.

three broad categories: UAVs, UGVs and Maritime Unmanned Systems (MUS).[106] The MUS classification is subdivided into Unmanned Surface Vehicles (USVs) and Underwater Unmanned Vehicles (UUV). Unmanned Systems also possess various levels of autonomy, to include remotely controlled, semi-autonomous, and fully autonomous operations.

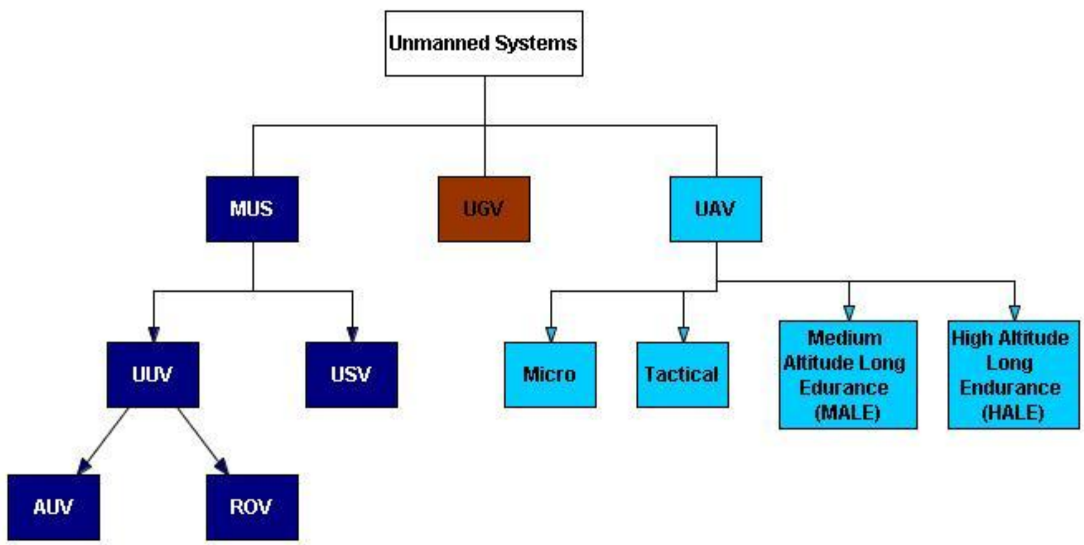

Figure 16 - Unmanned Systems Family Tree.

Source: Author.

UNMANNED AERIAL VEHICLES (UAV)

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[106] Maritime Unmanned System's is a recent classification used to encompass all unmanned systems that solely operated in the maritime environment. This has mainly been driven by the USN, which is attempting to ensure that the various MUS that are acquired are integrated in accordance with the *systems of systems or family of systems concept.* NATO has also commenced using this terminology. There is no literature or studies that indicate that there is a movement to make an umbrella classification for UGVs or AUVs at this time.

Within the unmanned systems family, the UAV continues to receive the most significant attention in terms of military and public awareness, R&D, operational testing and funding. For example, in the US DoD current and forecasted unmanned systems budget, UAVs consume ninety-four percent of the allocated unmanned systems funding for fiscal years 2011 through 2015. This percentage represents approximately thirty-three billion dollars, which includes R&D, operational testing, procurement, operations and maintenance.[107] These US budgetary figures are also supported by a recent industry analysis report, which estimates that the projected growth of the UAV marketplace for military and commercial use may achieve global sales approaching eighty-nine billion dollars, split between R&D and procurement over the next decade.[108]

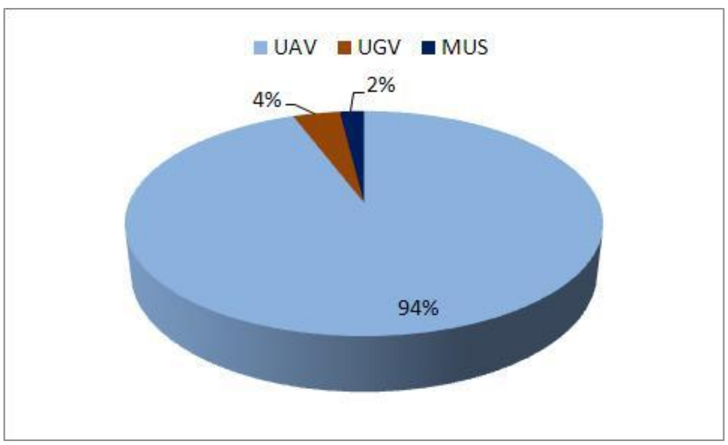

Figure 17 - US DoD FY 11-15 Budget for Unmanned Systems.

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[107] Department of Defense, Unmanned Systems Integrated Roadmap FY2011-2036 (Washington: DoD, 2011), 13, 21.

[108] Government Accountability Office, Unmanned Aircraft Systems: Measuring Progress and Addressing Potential Privacy Concerns Would Facilitate Integration into the National Airspace System (Washington: GOA, September 2012), 2.

Source: Unmanned Systems Integrated Roadmap FY2011-2036.[109]

As a result of available funding, the R&D level of effort, and industry investment; this has led to an increasing number of UAV systems capable of executing a wide range of missions. Today, there is a broad spectrum of UAVs that are currently operational and range in size from small man-portable UAVs to systems that are comparable to that of contemporary aircraft. The capabilities of UAVs are diverse and provide a variety of different operational capabilities. In the military context, the main operational employment of these systems is in the conduct of ISR or Intelligence, Surveillance, Targeting Acquisition and Reconnaissance (ISTAR) tasks. As a result of the success of UAVs during ISTAR missions, there has been significant recent development in the weaponization of UAVs, specifically Unmanned Combat Aerial Vehicles (UCAV), which are able to conduct strike missions. It is principally this military UAV capability which has triggered significant public debate, regarding the ethical employment of unmanned systems in military operations. While most UAVs are remotely controlled by a pilot at a ground control station, some have limited levels of autonomous capability, such as auto-pilot systems.[110] It is envisaged that future UAVs will likely possess more advance levels of autonomy, allowing for more independent operations.

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[109] Department of Defense, Unmanned Systems Integrated Roadmap FY2011-2036 (Washington: DoD, 2011), 13.

[110] James Kraska, "The Law of Unmanned Naval Systems in War and Peace," *Journal of Ocean Technology, Subsea Vehicles* 5, no.3 (July-October 2010): 61.

The biggest and most capable UAVs are the HALE UAVs, such as the Northrup Grumman RQ-4 Global Hawk; and the MALE UAVs, such as the General Atomics MQ-1 Predator and MQ-9 Reaper.[111] These UAVs have flight endurance times of approximately thirty hours (hrs) and can reach altitudes of 65,000 feet. Smaller Tactical-UAVs (TAUV) such as the Israeli manufactured Hermes-450, or the French manufactured SPERWER, have shorter endurances, and ranges of 125 to 250 km, and can operate at heights up to 15,000 feet.[112] The smallest systems of the UAV family are referred to as Micro-UAVs (MUAV), and are manufactured to be man-portable. MUAVs require no specific launching systems and are usually controlled from a lap-top by soldiers in the field. Although they have limited endurance, with approximately one hour of flight time, they have proved to be effective "for beyond line of sight scouting at ranges of up to five km."[113] Regardless of classification, UAVs have been widely used by coalition forces in Iraq and Afghanistan, supporting combat operations such as: CIED, convoy route surveillance, and more contentiously, strategic and operational level ISTAR and strike missions.

As with other nations, the CAF has been analysing, testing, and to some extent operating UAVs for a number of years. Defence Research and Development Canada (DRDC), has been testing UAVs and unmanned aircraft since the 1960s, and has been directly involved in advising the CAF on UAV R&D as it relates to future technical

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[111] Elizabeth Quintana, *The Ethics and Legal Implications of Military Unmanned Vehicles* (Royal United Services Institute, 2008), 2.

[112] Ibid., 2.

[113] *Ibid., 2.*

and operational requirements. Based on the developments in other nations, the Royal Canadian Air Force (RCAF) commenced the Joint UAV Surveillance and Target Acquisition System (JUSTAS) program in 2000. The objective of the JUSTAS project is to acquire a MALE UAV capability in order to enhance the CAF ISTAR capabilities. While the JUSTAS project was ongoing; combat operations in Afghanistan were intensifying, and the CAF was becoming aware that it was exposing combat personnel to excessive risk due to operational deficiencies in its tactical and operational level ISTAR capabilities.[114] Consequently, based on the urgent operational requirement, the CAF rapidly acquired the CU-161 SPERWER TUAV to support the ongoing combat operations. Initially this acquisition was seen as a significant increase in operational capability, as field commanders now had access to tactical and operational level ISTAR data. Unfortunately, this UAV programme experienced numerous problems, including technical, environmental and support issues. These issues were mainly due to the rapid acquisition process, which prevented that Army and the RCAF's requirements and procurement staffs from fully understanding the necessary operational requirements in order to satisfy the existing capability deficiency. Compounding this issue was the lack of institutional UAV knowledge required to employ and maintain this capability within the CAF.

While the CAF continued to work through the SPERWER UAV issues, the Right Honourable John Manley released his report, entitled *Independent Panel on*

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[114] *Department of National Defence, 11500-1 (DAR 8),* Statement of Operational Requirement: Joint UAV Surveillance and Target Acquisition System (JUSTAS) *(Ottawa: DND, 2011),* 2.

*Canada's Future Role in Afghanista*n. The report recommended that in order to "ensure the safety and effectiveness of the Canadian contingent, the Government should also secure . . . . high-performance Unmanned Aerial Vehicles (UAVs) for ISR before February 2009."[115] In response to this recommendation, the government awarded through a competitive bidding process two UAV provision of service contracts; the first to MacDonald Detwiller and Associates, for the provision of a leased Israeli Aerospace Industries Heron MALE UAV; and the second contract awarded to ING Engineering, for the provision of a leased Boeing Scan Eagle TUAV. Both contracts included in-theatre service support, and training to CAF operators. The contracts for these services, under the name "Project NOCTUA", ended on completion of the combat mission in Afghanistan.[116] Currently the JUSTAS Project is still ongoing, but it is contending with a constricting defence budget, other competing high-priority CAF acquisition projects, and the challenge of identifying the human resource demand on the RCAF in order to introduce a permanent UAV capability within the CAF.

The RCN has also been examining its future UAV operational requirements. It has conducted numerous trials with TUAVs embarked in warships in order to compliment the ships own organic ISR sensors and the maritime helicopter capability. Specifically, the RCN has looked at various TUAVs, as well as Vertical Take-off and

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[115] John Manley, *et al., Independent Panel on Canada's Future Role in Afghanistan* (Ottawa: PWGSC, January 2008), 35, 38.

[116] David Neil, "Project Noctua: A Model for Enhancing NATO UAV Capability," *The Journal of the JAPCC*, no. 13 (2011), 25.

Landing UAVs, such as the MQ-8 Fire Scout, which are both suitable for shipboard deployment in support of the RCN's routine ISR tasks. Successful technology demonstrations and naval exercises using operational scenarios have proven very successful. This success, has led to Her Majesty's Canadian Ship (HMCS) Charlottetown, embarking a Scan Eagle TUAV with a UAV detachment in support of her recent mission to the Mediterranean for Operation Active Endeavor.[117] Although the UAV proved to be a very capable force multiplier, to date there is no follow-on UAV acquisition project planned for the RCN. Notwithstanding this, the RCN is planning to ensure that designs for its future warships account for the requirement to operate organic unmanned systems.

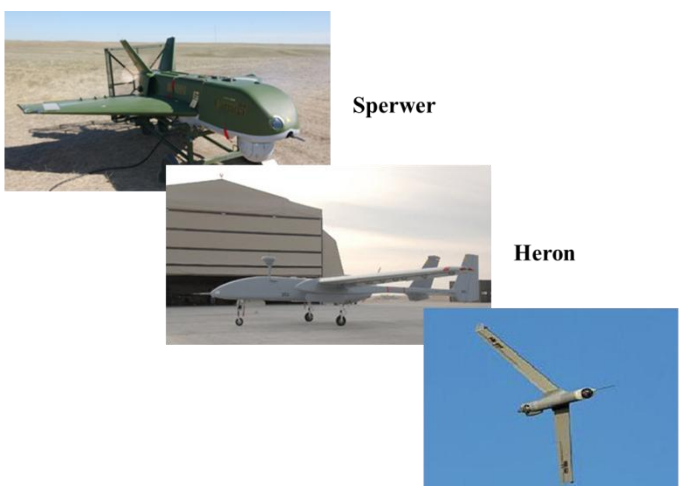

Figure 18 - UAVs operated by the CAF.

Source: RCAF[118,119] and Boeing.[120]

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[117] Chris Thatcher, "Evaluating an unmanned asset," *Vanguard: The Forum for Canada's Security and Defence Community Online*, 29 August 2011. Accessed 10 February 2013. http://vanguardcanada.com/evaluating-an-unmanned-asset/.

[118] Royal Canadian Air Force, "CU-161 Sperwer," accessed 10 February 2013. http://www.rcaf-arc.forces.gc.ca/v2/equip/hst/cu161/index-eng.asp.

Notwithstanding the current status of the RCN's UAV intentions, there is promising work being conducted at the DRDC Valcartier laboratory on a light-weight electro-optic sensor system suitable for deployment in a UAV. The Joint Multi-Mission Electro-Optical System is designed to detect small surface and subsurface targets in a range of sea states. Initial trials conducted in collaboration with the USN's Office of Naval Research has demonstrated that the system is capable of detecting shallow-water sea mines, small vessels and submerged submarines that are close to the surface. Embarking this type of system in an organic UAV, would give a warship a credible in-stride sea mine avoidance and an enhanced ISR and ASW capability.

UNMANNED GROUND VEHICLES (UGV)

UGVs are currently providing important supporting capabilities to land combat and police forces engaged in combat and domestic security operations. From recent experiences in Afghanistan, as well as domestic security operations, such as *Operation Podium*,[121] the Canadian Army has gained extensive experience in the operational use of UGVs. Currently the Army maintains two different types of UGV systems. Specifically the Remotely Operated Mechanical Explosive Clearance

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[119] Royal Canadian Air Force, "CU-170 Heron," Accessed 10 February 2013. http://www.rcaf-arc.forces.gc.ca/v2/equip/hst/cu170/index-eng.asp.

[120] Boeing, "ScanEagle Unmanned Aerial Vehicle," Accessed 10 February 2013. http://www.boeing.com/history/boeing/scaneagle.html.

[121] Operation Podium was the CAF's support to the RCMP-led domestic security operations for the 2010 Vancouver Olympic and Paralympic Games.

System (ROMECS) designed to counter the anti-personnel and anti-tank mine threat; and the smaller Vanguard UGV designed primarily for Explosive Ordinance Disposal (EOD)/Improvised Explosive Device (IED) and reconnaissance tasks.

Figure 19 - Canadian Army UGVs. ROMECS (left) and the Vanguard (right) UGVs. Sources: Rheinmetall Defence Canada[122] and Allen-Vanguard.[123]

It has been assessed that UGVs, "when used to their maximum capability, are decreasing the amount of frontline personnel and equipment losses, and can significantly enhance the capabilities of combat units on the modern battlefield."[124] Notwithstanding the recent success experienced with UGVs in military operations, many militaries, including Canada gave up on UGVs in the 1990's due to the perception that bomb disposal and EOD tasks were more of a domestic policing and security function. As a result of lessons learned from combat operations in Iraq and Afghanistan, military commanders now realize that the modern day battlefield

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[122] Rheinmetall Defence Canada, "Electronic Systems," accessed 9 February 2013, http://www.rheinmetall.ca/en/rheinmetall_canada/systemsandproducts/electronicsystems/electronic-systems.php.

[123] Allen-Vanguard, "Remotely Operated Vehicles – Robots," accessed 09 February 2013. http://www.allenvanguard.com/en-us/products/remotelyoperatedvehiclesrobots.aspx.

[124] Serkan Kilitci, and Muzaffer Buyruk, "An Analysis of the Best Available Unmanned Ground Vehicle in the Current Market with Respect to the Requirements of the Turkish Ministry of National Defense," (MBA Professional Report, Naval Post Graduate School, 2011), 9.

includes such hybrid threats as IEDs and urban warfare. Consequently, due to rising casualties, most western military forces found themselves having to face the "extremely difficult and very expensive task to rapidly re-establish CIED capabilities within their forces."[125] During the 2011 Defence IQ Military Robotics Conference in London, the CAF Director of EOD and CIED Combat Support, stated that the CAF is committed to its UGV capability by maintaining its current systems, as well as procuring two more vehicle types, one to enhance the CAF EOD and CIED capability, and the second to support the CAF chemical, biological, radiological, and nuclear reconnaissance (CBRN) capability.[126] Notwithstanding this commitment, the Canadian Army has been hindered by a lack of vision or master implementation plan for current and future operational UGV requirements. This was mainly due to the urgent operational requirement to rapidly field an EOD and CIED UGV capabilities into operations in Afghanistan. Consequently, this was a similar situation to the SPERWER UAV acquisition by the RCAF.

Now that the combat role in Afghanistan has ended, the Army can now refine and develop its current and future UGV operational requirements. This will enable the Army to conduct a thorough integration of these systems into its inventory, and bring them to full operational capability. In doing so, it will also enable commanders and individual troops to understand their capabilities in order for them to develop the

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[125] Sheppard Media Unmanned Vehicles Online, "Canadian Army plans for expansion of UGV capabilities," accessed 09 February 2013, http://www.shephardmedia.com/news/uv-online/canadian-army-plans-for-expansion-of-ugv/.

[126] *Ibid.*

doctrine for tactical employment of UGVs. These lessons learned will be of significant value to both the RCAF and RCN as they prepare to acquire UAVs and AUVs.

The operational use of current UGVs and the advancements of new UGV designs continue to increase. In a recent market survey, it was assessed that there will be a continued global demand from militaries and domestic security organizations for the procurement of UGVs for the foreseeable future. The report also assessed that within Canada, the UGV market place can expect an annual compounded growth rate of approximately four percent between 2011 and 2021.[127]

UGVs have been primarily used and developed for EOD and CIED operations, which include search, detection, reconnaissance, surveillance and EOD/CIED target acquisition missions. In the future, UGV system developers in conjunction with military planners are also considering "perimeter surveillance, vehicle checkpoints, house clearance searches, logistics, fire-fighting, casualty recovery, mobile communications links, mobile power supplies and decoy targets, as potential future UGV capabilities."[128] UGVs are primarily controlled remotely via an umbilical cable or radio link, although some UGVs can conduct simple autonomous operations. On the spectrum of autonomy, current autonomous UGVs are considered

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[127] VisionGain, *The Unmanned Ground Vehicles (UGV) Market 2011-2021: Military Robots for EOD & Counter-IED* (London: VisionGain Ltd, 2011), 101.

[128] NATO Research and Technology Organization, RTO-TR-HFM-078, *Unmanned Military Vehicles – Human Factors of Augmenting the Force* (Brussels: NATO,

simple in regards to their level of autonomous behavior in relation to their UAV and MUS cousins. Notwithstanding this, UGVs have proven more than capable of navigating an environment without human intervention, conducting simple tasks, detecting objects of interest such as IEDs, and avoiding threats that can be dangerous to themselves, friendly combatants or innocent non-combatants.

UGVs have proven themselves to be effective force multipliers on the modern battlefield, particularly in the EOD, CIED and urban warfare roles. Although there is no quantitative data available to report on how many soldiers they have saved or IED attacks they have prevented, the fact remains that these systems went from developmental to operationally fielded systems in relatively short order. Furthermore the demand for increased numbers, as well as increased capabilities continues to increase. At a 2008 conference on the legal and ethical limitations of unmanned systems, it was assessed that there were in excess of 4,000 UGVs being employed by coalition forces in Iraq and Afghanistan.[129] In comparison, by 2011, the number of systems had increased to 8,000.[130] Since the commencement of Operation Iraqi Freedom, it is estimated that UGVs have executed in excess of "125,000 CIED/EOD missions."[131] In the conduct of these CIED/EOD missions, UGVs detected and countered over 11,000 IEDs. With the obvious demand increasing, future UGV roles

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[129] Elizabeth Quintana, *The Ethics and Legal Implications of Military Unmanned Vehicles* (London: Royal United Services Institute, 2008), 2.

[130] COTS Journal Online. "Ambitious Road Ahead for Military Robotics Technology, April 2012," accessed 23 February 2013, http://www.cotsjournalonline.com/darpa?&lang=en_us&output=json.

[131] *Ibid*.

may consist of: direct fire combat, CBRN, logistics support, and manoeuvre support roles.[132]

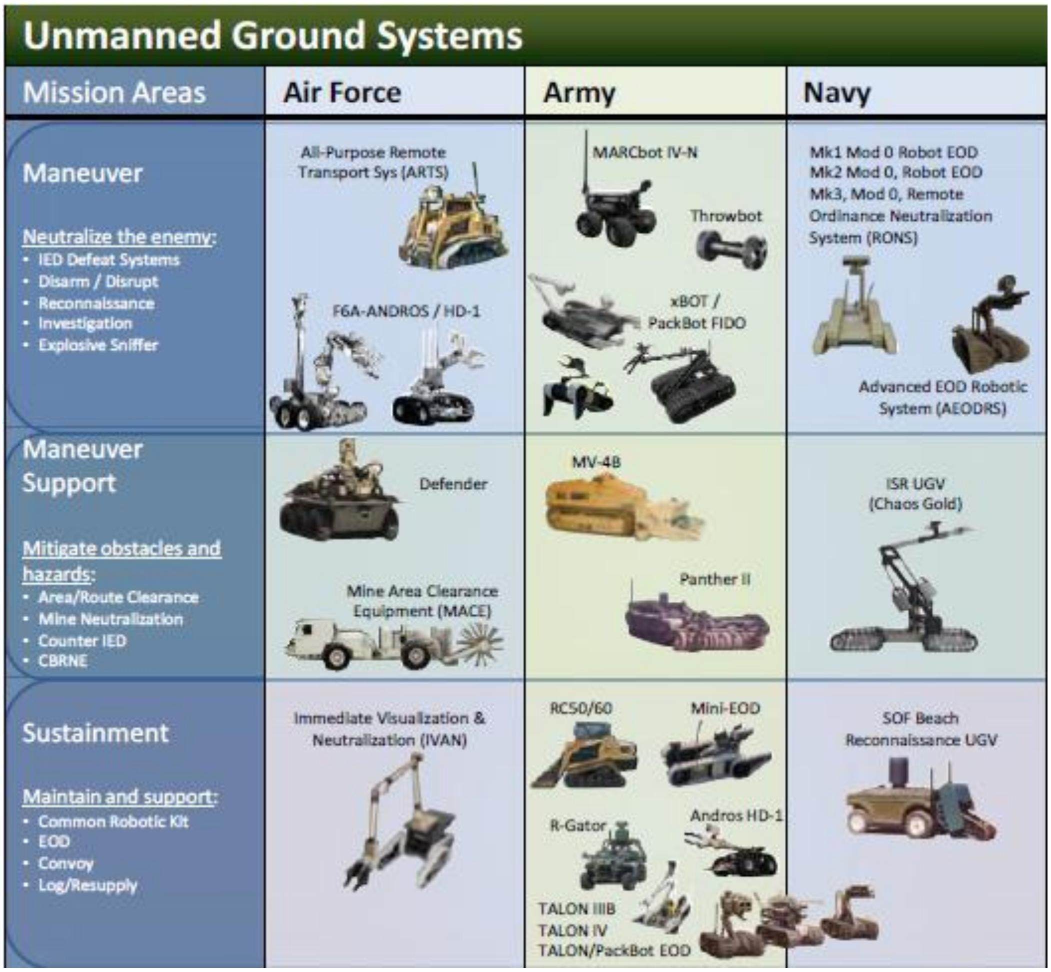

Figure 20 - United Stated Military UGV Family of Systems.[133]

Source: Unmanned Systems Integrated Roadmap FY 2011-2036.[134]

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[132] Department of Defense, Unmanned Systems Integrated Roadmap FY 2011-2036 (Washington: DoD, 2011), 22-23.

[133] The USN is a significant employer of UGVs. USN UGVs support the Marines, USN SOF, and the USN Construction Battalion (CBs or SeaBees). In the RCN, the Clearance Divers operate the Vanguard UGVs as part of the Joint CIED/EOD Task Force.

[134] *Ibid.*, 24.

In the naval context, there has been significant interest within the amphibious and NMCM communities regarding the potential uses of AUV designs that have been inspired by UGVs. For example, the US Marines and Special Operations Forces (SOF) have been experimenting with hybrid vehicles that can operate in the beach and surf zones in order to covertly clear anti-invasion obstructions and mines in support of covert SOF insertions or amphibious landings.[135] Similarly, there has been increasing interest in using unmanned systems to assist in port and harbour protection. The NATO Undersea Research Center and US Office of Naval Research have been collaborating on a technology demonstration vehicle that combines the best attributes of a UGV, ROV and AUV, which will be able to conduct autonomous inspections of ships hulls, and underwater port infrastructure.[136] If successful this type of hybrid vehicle will significantly enhance underwater port and harbour security.

MARITIME UNMANNED SYSTEMS

It does not matter if it is aircraft, ships or information via undersea cables; they all depend on a secure maritime environment for safe transit. The vast majority of global data, people, goods, and services that sustain the world’s economy; travels

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[135] National Research Council Report, *Autonomous Vehicles in Support of Naval Operations* (Washington: National Academies Press, 2005), 137.

[136] Naval-Technology.COM, “The Automated Future of Hull Inspection,” accessed 24 February 2013, http://www.naval-technology.com/features/feature129863.

above, across and under the maritime domain.[137] With emerging threats such as piracy, natural resource disputes, drug trafficking, and weapons proliferation; a rapid and deployable maritime response capability is needed in all maritime regions to ensure global security and world order. As a result, many navies are expanding the spectrum of missions supported by MUS in the maritime environment.

MUS can be defined as unmanned vehicles that operate on or below the ocean surface and can be sub-divided into USVs and UUVs. A recent NATO study concluded that MUS "have the potential to provide critical enabling capabilities for current NATO maritime missions that can improve Alliance security and stability."[138] MUS like other unmanned systems are considered as force multipliers and can increase the operational capability in the process of conducting maritime operations that were previously not possible using manned ships and submarines. Consequently, like the UAV and the UGV, MUS have the potential to save lives by reducing risks to personnel and ships, by conducting tasks that are deemed dull, dangerous or dirty. They also have the potential to provide persistent surveillance, and reduce overall operating costs.

Notwithstanding the future potential of MUS, there still is significant amount of work to be done to bring these systems into the conventional realm. In comparison

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[137] Department of Defense, *Unmanned Systems Integrated Roadmap: FY 2011-2036* (Washington: DoD, 2010), 24.

[138] NATO, Combined Joint Operations from the Sea Centre of Excellence (CJOS/COE), *Guidance for developing Maritime Unmanned Systems (MUS) capability* (Norfolk: NATO, 9 July 2012), 43.

with their UAV counterparts, MUS have lagged behind in development and technological maturity.[139] There are a number of reasons that can be attributed to this situation, but the primary reason has been the effects of the challenging nature of the maritime environment on technology. Furthermore, as can be seen in Figure 17, these systems in comparison to UAVs and UGVs, receive the smallest amount of US government funding for R&D, operational test and evaluation, procurement, and operations and maintenance.

Finally, there is a lack of military and public awareness regarding the current capabilities of MUS. This lack of awareness can be attributed to not having the level of controversy as UAVs, nor have they been seen combating the ever present IED threat, such as UGVs in places such as Afghanistan. Nevertheless, where UAV and UGVs military operational requirements have driven their development and procurement cycles; MUS, specifically ROVs and AUVs, have been championed by commercial interests such as offshore oil and mining sectors. This has allowed these systems to mature outside the military development and procurement streams. Consequently, naval forces can now take advantage of maturing commercial technologies with very little incremental development costs in order to transition these systems to be able to conduct certain traditional naval warfare tasks.

Unmanned Surface Vehicles

[139] *Ibid*., 1.

USVs operate with continuous contact with the surface of the water, and can include self-propelled conventional hull craft, hydrofoils, and semi-submersibles.[140] The USV can either be completely autonomous or operated remotely through a radio or telecommunication data link to a command station ashore or embarked in a host ship. Although USVs have been in existence since the Vietnam War, they have not developed as quickly within the military environment as some of the other unmanned systems. To date the majority of USVs currently in use are used primarily as "naval gunnery and missile targets."[141] For instance the RCN regularly uses Meggitt Hammerhead and Barracuda USVs, designed specifically as high speed Fast Inshore Attack Craft targets during its domestic and international naval exercises.

Figure 21: RCN USV Targets. RCN Hammerhead (left) and Barracuda (right) USV targets.

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[140] Program Executive Office Littoral and Mine Warfare, *The Navy Unmanned Surface Vessel (USV) Master Plan* (Washington: Department of the Navy, 23 July 2007), 6-7.

[141] S.J. Corfield and J.M. Young, "Unmanned Surface Vehicles: Game Changing Technology for Naval Operations," in *Advances in Unmanned Marine Vehicles,* ed. G.N. Roberts and R. Sutton (London: Institution of Engineering and Technology, 2008), 312.

Source: Meggitt Training Systems Canada.[142]

Notwithstanding the slower progress that USVs have achieved compared to other types of unmanned systems, it is expected that USVs will start to play a more significant role within the MUS family as the USN is stepping up its USV R&D, operational test and evaluation, and insertion programmes. The slower development progression can be attributed mainly due to the lack of a perceived non-military role. Hence they have also not been embraced by industry and academia like their ROV and AUV counterparts. Additionally, the USV Master Plan was the last of the US unmanned systems master plan documents to be completed by the US Department of the Navy. However, the USV Master Plan provides the USN with the required direction to proceed with a number of different types of USVs, in order to conduct the following naval missions in order of developmental priority: NMCM, ASW, Maritime Security, Surface Warfare, SOF Support, Electronic Warfare, and Maritime Interdiction Operations Support.[143]

In support of the USV Master Plan, the Littoral Combat Ship (LCS) programme was intending to integrate major USV systems into the LCS as part of the ship's mission package concept. The LCS is a corvette-sized vessel, intended to replace the capabilities of the USN's fleet of Frigates, NMCM Vessels and Patrol

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[142] Meggitt Training Systems Canada, "Naval Targets," accessed 08 February 2013, http://www.meggittcanada.com/products/naval-targets/.

[143] Program Executive Office Littoral and Mine Warfare, *The Navy Unmanned Surface Vessel (USV) Master Plan* (Washington: Department of the Navy, 23 July 2007), 11.

Boats into one platform. The combination of these capabilities is intended to be accomplished by the embarkation of the following three interchangeable *Plug and Play* mission modules: NMCM, ASW, and Anti-Surface Warfare modules. Within each mission module, USVs were significant components. Unfortunately, due to significant technical challenges, which pertain to USV size, weight and operational capabilities, some of the USV development programmes have been delayed or are awaiting programme reviews.[144]

Other than the USVs currently used as targets; the RCN in collaboration with DRDC conducted a five year technology demonstration project in order to determine the feasibility of using a semi-submersible USV for NMCM operations. The project developed the Remote Minehunting System (RMS), based on the ISE DORADO Semi-Submersible equipped with towed variable depth multi-beam side scan sonar. This minehunting USV was able to conduct operations up to eight km from its control station, at minehunting depths of 200 m. During the trial, the system met or exceeded most of the stated operational requirements.

[144] Ronald O'Rourke, *Navy Littoral Combat Ship (LCS) Program: Background and Issues for Congress* (Washington: Congressional Research Service, 2012), 14, 16, 41.

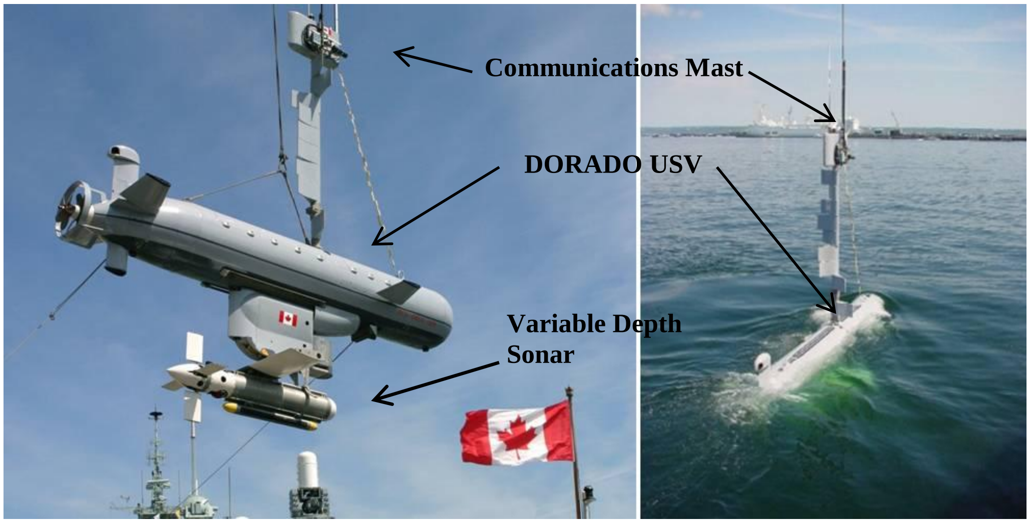

Figure 22 – DORADO Minehunting USV.

Source: ISE Inc.[145]

Based on its success, the DORADO USV was used extensively for security operations during the months leading up to, and including Operation Podium.[146] Unfortunately, the Dorado USV's major flaw was its size and overall weight of approximately 7,000 kilograms (kg). With issues similar to that being experienced in some of the USN USV programmes, this size and weight issue raised major technical challenges in regards to launch and recovery, and overall deployability.

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[145] International Submarine Engineering, "DORADO: Semi-Submersible Minehunting Vehicle," accessed 24 February 2013, http://www.ise.bc.ca/dorado.html.

[146] Department of Nation Defence, "Canadian Joint Operations Command: Past Operations," accessed on 9 February 2013, http://www.cjoc-coic.forces.gc.ca/cont/po-op-eng.asp.

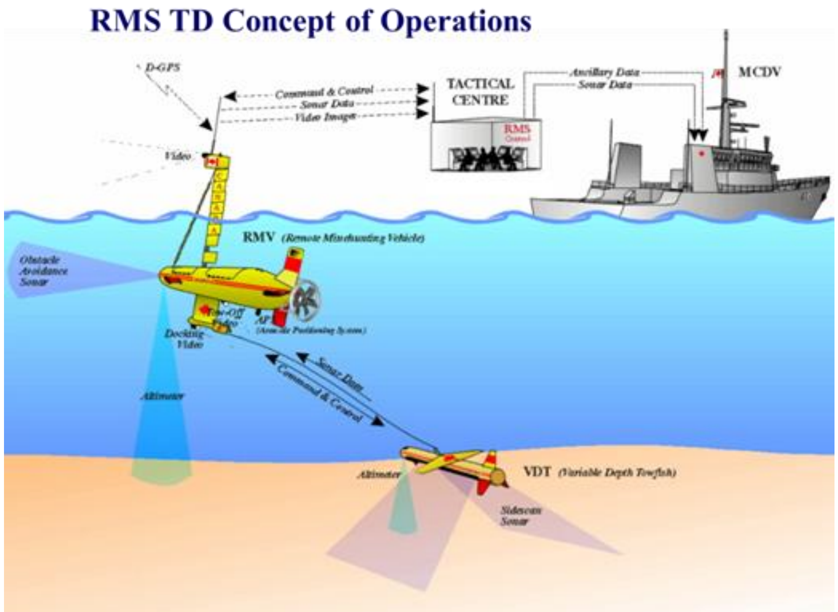

Figure 23 - RMS TDP Concept, using a semi-submersible USV.

Source: RCN.

CHAPTER FIVE

UNMANNED UNDERWATER VEHICLES

WHY UNMANNED

The panacea of future NMCM capability is to ultimately “remove the man from the minefield.”[147] In order to attain this goal, navies and their associated R&D organizations are conducting significant investments into UUV systems and concept development. Unlike other unmanned systems discussed earlier, UUV development has primarily been driven by the commercial and academic sectors, where UUVs have already proven their utility. Consequently, over the last decade there has been an increase of commercial off-the-shelf (COTS) UUVs introduced into the naval warfare operation of NMCM. The ongoing developmental process of UUVs has thus reversed the traditional *military to civil* direction of technology transfer.

There are two kinds of UUVs used in civilian and military operations; the most common being the ROV and the second type being AUVs.[148] An ROV is normally controlled by Pilot via a tether or umbilical that links the ROV to a control station on a support ship. Conversely, an AUV is characteristically defined as an

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[147] Expeditionary Warfare Division. *21st Century US Naval Mine Warfare: Ensuring Global Access and Commerce* (Washington: United States Navy, 2009), 21.

[148] It should be noted that the USN does not use this definition. It considers the term UUV and AUV to be interchangeable. For example the USN UUV Master Plan does not discuss any of the USN’s ROV requirements. This does cause some confusion when NATO partners deal with the USN.

untethered submersible that possesses a level of autonomy that requires little to no human interaction during a mission.[149] Notwithstanding these basic definitions, recently distinctions between the two types of vehicles have become increasingly blurred, mainly through continuous spiral developments in vehicle technology and design.[150]

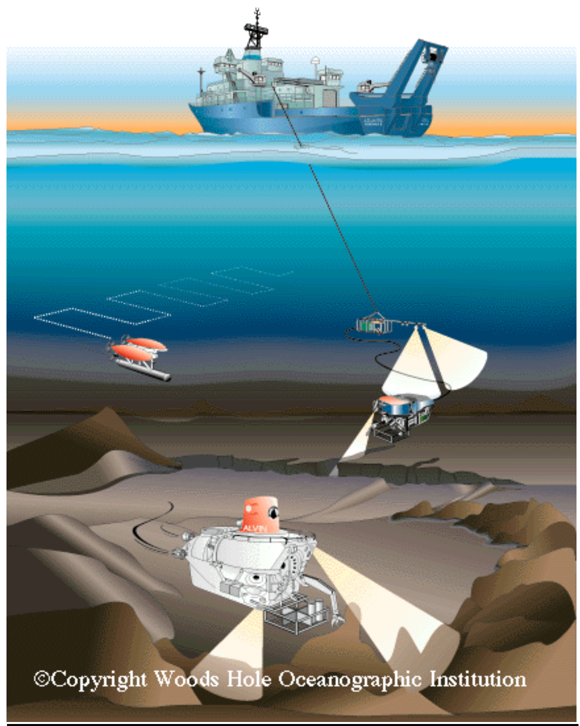

Figure 24 – UUV Concept. A Woods Hole Oceanographic Institution conceptual image displaying the famous manned submersible ALVIN, working with the AUV SENTRY (top left), and the ROV JASON (top right). All three systems were used in collaboration during the 2010 Titanic Expedition. Note the tether for the ROV.

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[149] There are some AUVs other that hybrid vehicles that uses a thin wire, similar to that used in a wire guided torpedo or missile, to send real-time data back to a control station, this would not be considered a tethered vehicle. This technology is not wide-spread and this research has found that this is not a major design driver.

[150] Recently there has been a push by the industrial sector to start combining the best qualities of AUVs and ROVs into one vehicle. This is based on industries desire to be more cost efficient. Because this is a relatively new initiative, there are no identified military applications for a hybrid vehicle yet.

Source: Woods Hole Oceanographic Institution.[151]

ROVs have been in service with most navies for a number of years, and their use is considered relatively mature. Their operational uses span from conducting hull and underwater inspections; Search and Rescue (SAR); and NMCM. If one was to attempt to draw a comparison to other unmanned systems, the ROV could be considered the amphibian cousin of the UGV described in Chapter Four. In regards to AUVs, their naval utility is still relatively immature and under development. Notwithstanding the current state of AUV maturity; due to rapid advancements in commercial technology; and naval interest, this maturity gap is rapidly diminishing. The first operational use of AUVs was demonstrated during Operation Iraqi Freedom in 2003, where the USN, RN, and the RAN; used REMUS 100 AUVs to conduct covert NMCM operations in the vicinity of the Iraqi sea ports of Umm Qasr, Az Zubayr and Karbala. During these operations the AUVs successfully searched over "two and a half million m^2 of inland waterways to enable three ports to be readied for incoming humanitarian shipments."[152] AUVs can be compared to UAVs in that they both manoeuvre in three dimensions in their respective environments. But the comparison really stops there, for the AUV primarily executes its mission with very little human interaction and cannot provide real-time imagery that the UAV is well known for. At the end of the day, although it is important to understand the

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[151] Woods Hole Oceanographic Institution, "Deep Submergence Laboratory - Vehicles," accessed on 13 April 2013, http://www.whoi.edu/page.do?pid=23557.

[152] Global Security.Org, "Unmanned Underwater Vehicles," accessed 24 February 2013, http://www.globalsecurity.org/intell/systems/uuv.htm.

relationships and comparisons between systems, one must understand that the environments really drive the particular mission.

REMOTELY OPERATED VEHICLES

Within the realm of the underwater unmanned systems family, the ROV possesses the most mature technology and has the longest history of operational use. ROVs have been supporting undersea research, exploration, industry and military operations for decades. This major field of technology, in which non-military use has outstripped the original military lead, enables human intervention and manipulation in the undersea environment. Initially it was the military that invested in R&D during the 1960's, which resulted in a few dedicated and single role ROV systems. However, it was not until the offshore oil and gas, and seabed mining industries started to express interest into the practical use of ROVs in the 1970's and 1980's, that the true technological evolution of ROVs took place.[153] Since this period, ROV systems have become common tools used in the service of undersea science and industry; and due to their impressive general purpose capabilities, combined with the ability to work in the world's harshest environment, have regained the interest of naval salvage, EOD and NMCM specialists.

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[153] Don Walsh, "Thirty Thousand Feet and Thirty Years Later: Some Thoughts on the Deepest Ocean Concept," *Marine Technology Society Journal, vol. 24 no, 2 (June 1990), 7-8.*

Although the use of ROVs in the undersea environment is now a common practice, some of the earlier examples of ROV use, conjure up images of Jules Verne proportions. For example the USN, used a ROV in a massive search and recovery operation for a lost nuclear weapon, in the offshore waters of Spain in 1966. The Cable-controlled Undersea Recovery Vehicle MK1 (CURV I) was developed in 1960 to recover torpedoes at a weapons range off California. CURV I successfully recovered the nuclear weapon in approximately 1,600 m of water, thus averting a major disaster and public relations nightmare for the US.[154] Follow on models of the CURV I, successfully rescued the two-man crew of the manned mini-submarine PISCES III that sank in 500 m of water off the coast of Ireland in 1973,[155] followed in 1976 by conducting the initial survey of the wreck of the MV Edmund B. Fitzgerald in 150 m of water in Lake Superior.

More recently, ROVs continue to be used extensively in underwater salvage, offshore petroleum, mining, exploration and research. For example, the Woods Hole Oceanographic Institution's ARGO ROV, was the primary underwater system used in Robert Ballard's 1985 search for the Titanic wreck site.[156] The Argo ROV was able to conduct a continuous 24/7 search, detection, localisation and inspection operation of the wreck site at depths of 4,000 m below the host research ship. ROVs were also

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[154] R.A. Geyer, *Submersibles and Their Use in Oceanography and Ocean Engineering* (Amsterdam: Elsvier Scientific Publishing Company, 1977), 25.

[155] Richard Ellis, *Deep Atlantic: Life, Death, and Exploration in the Abyss* (New York: Lyons Press, 1998), 77-78.

[156] Woods Hole Oceanographic Institution (WHOI), "Ships & Technology used during the Titanic Expeditions," accessed 16 February, http://www.whoi.edu/page.do?pid=83577&tid=3622&cid=130989.

employed during the 2010 response to the massive British Petroleum Deepwater Horizon oil spill in the Gulf of Mexico. During this disaster response operation, multiple ROVs played a critical role in the installation of the well-head capping system, which was require to stop the flow of raw crude into the Gulf. These ROVs operating at depths of over 1,500 m featured fully maneuverable manipulator arms able to operate tools in a similar fashion as a human diver.[157] To demonstrate the value of these systems, the maximum depth for a human diver is 100 m, when using mixed-gas surface supplied systems, and even at this maximum depth the diver is limited to a very short duration of work, due to affects to compression on the human body.[158]

In the context of unmanned systems, ROVs are regulated second only to that of UAVs. UAVs are regulated much like commercial and private aircraft by national and international regulations, mainly due to the complexity of operating in national and international airspace. ROVs on the other hand have very little governmental regulations, but are governed by the codes and practices of the globally recognized, International Marine Contractors Association (IMCA). The IMCA regulates and defends the internal interests of the commercial offshore and marine industry, including activities such as: marine operations; diving; ROVs; and offshore

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[157] British Petroleum, "Remote Operated Vehicles, Deepwater Horizon Accident," accessed 16 February 2013, http://www.bp.com/sectiongenericarticle800.do?categoryId=9036600&contentId=7067604.

[158] National Defence, DAOD 8009-1, Canadian Forces Diving - Organization and Operating Principles (Ottawa: DND Canada, 2006). Accessed 17 February 2013, http://www.admfincs.forces.gc.ca/dao-doa/8000/8009-1-eng.asp.

survey/positioning systems.[159] For example the IMCA, has developed a ROV classification system that is recognized by the military and commercial underwater sectors to include the following classes: Class I – Observation; Class II – Observation with Manipulator Arm capability; Class III – Work Class; Class IV – Bottom Crawlers; and Class V – Prototype and Development ROVs.[160] Consequently unlike other unmanned systems, ROV development and employment issues are driven by non-military organizations. Further to this, the IMCA has established the recognized training, certification, environmental and classification standards. In many ways this has been a benefit for the military, as the main effort for R&D, and capability innovation has been borne by commercial interests and not the military-industrial complex. This has been advantageous in a period of shrinking defence budgets, and a trend that will continue to be seen in further unmanned system developments such as with AUVs.

The RCN maintains a credible underwater and seabed intervention capability to support such activities such as: submarine SAR, underwater salvage, EOD, seabed object inspection, and support to other government departments. Initially these tasks were conducted by naval clearance divers augmented with the Naval Diving Ship, HMCS Cormorant, equipped with a PISCES IV and a SDL-1 manned submersibles

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[159] International Marine Contractors Association, "IMCA Factsheet, the IMCA Message," accessed 18 February 2013, http://www.imca-int.com/documents/factsheets/IMCA-fs-Message.pdf.

[160] *Ibid.*

capable of operating at depths of 2,000 and 1,500 m respectively.[161] When the RCN decided to decommission HMCS Cormorant in 1998, it also decided to replace its manpower and maintenance intensive manned submersible capability with various commercial ROVs to conduct the above seabed intervention tasks. In doing so, the acquisition of ROVs has increased the RCN's flexibility in being able to execute its seabed intervention tasks, due to the requirement for the new ROVs to be platform independent. As a result, the ROVs are able to be embarked in the smaller diving tenders, the Kingston Class patrol ships, other government department vessels, and commercial vessels of opportunity.

Currently, the RCN possesses three ROV systems to cover its assigned seabed intervention tasks. The largest and most capable ROV in the RCN inventory is the Deep Seabed Intervention System (DSIS); which was specifically acquired to replace the manned submersible capability. The DSIS is a Class III Work Class ROV capable of diving to 2,000 m, and is capable of carrying a 100 kg payload, or conversely recovering an object of the same weight.[162] It is equipped with sonars, video, and two manipulator arms. The whole system, which includes the ROV, Launch and Recovery System, and a twenty foot containerized control room, weighs approximately 19,000 kg. Notwithstanding this significant weight, this system can embark in most oceangoing vessels. In order to provide more flexibility, the Navy followed the DSIS

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[161] Jane's, *Jane's Fighting Ships 1996-97*, ed. Captain Richard Sharpe RN (Coulsdon: Jane's Information Group, 1997), 93.

[162] International Submarine Engineering, "HYSUB 50 – 2000," accessed 22 February 2013, http://www.ise.bc.ca/hysub50-2000.html.

acquisition by acquiring Class II – Observation ROVs, which are significantly smaller in size and can deploy in any vessel. The Bottom Object Inspection Vehicle (BOIV) can dive to 300 m; and the Seabotix ROV has a maximum operating depth of 950 m.[163,164] In both cases; the Class II ROVs are equipped with sonars, underwater cameras and small manipulator arms.

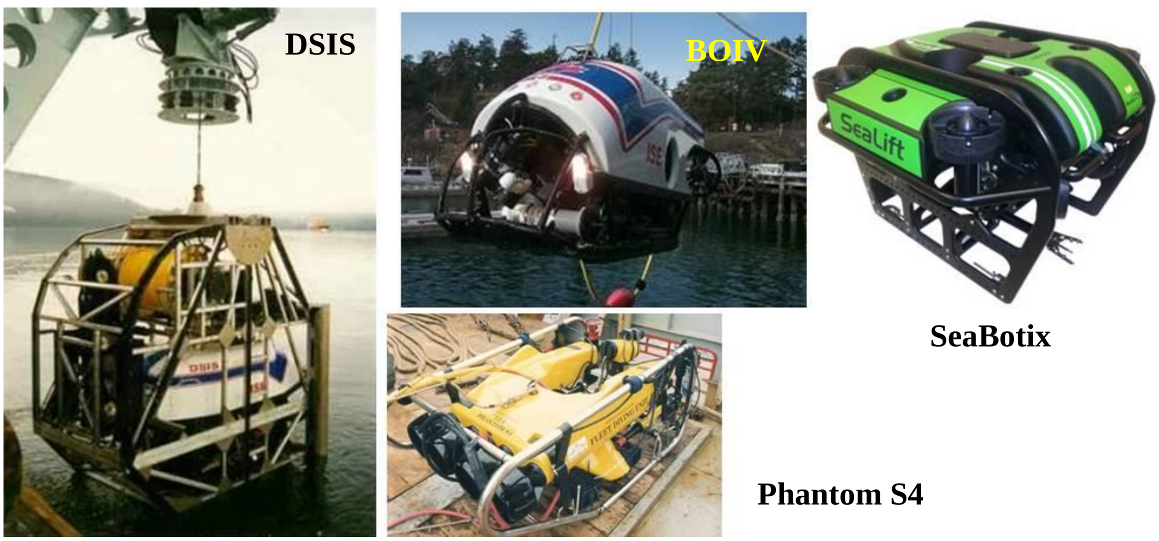

Figure 25 - RCN ROVs.

Sources: ISE Ltd, SeaBotix Inc, and Deep Ocean Engineering.

These ROVs have enabled the RCN to maintain the seabed intervention tasks assigned to it, and have been used successfully in a multitude of missions and operations. For example, during Operation Persistence, the CAF response to the

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[163] International Submarine Engineering, "Trailblazer 25 MCM ROV," accessed 22 February 2013, http://www.ise.bc.ca/TrailBlazer/ISE_Trailblazer_MCM_ROV_Datasheet_May11.pdf.

[164] SeaBotix, "vLBV-10 SeaLift," accessed 22 February 2013, http://www.seabotix.com/products/vlbv-10.htm.

Swiss Air Flight 111 crash off the coast of Nova Scotia on 2 September 1998,[165] the DSIS, BOIV and Phantom 4[166] ROVs played an integral part in the initial search and follow on survey and recovery operations of the underwater crash site. In 2000, the DSIS ROV was used in a major submarine rescue exercise, where the ROV was able to insert emergency life support pods in to the escape hatch of a disabled submarine on the seabed.

Figure 26 – ROV Operations. Two Kingston Class Ships positioned over a disabled submarine during a SUBSUNK Exercise. HMCS Glace Bay (right) has the DSIS deployed.

Source: ODIM Brooke Ocean Technology.[167]

Previously only deployable by divers, the life support pods are a critical survival system in order for a disabled submarine to maintain its life support systems while it

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[165] Stephen Kimber, *FLIGHT 111 the Tragedy of the Swissair Crash* (Toronto: Random House of Canada, 1999), 105.

[166] The Phantom 4 ROVs, were replaced by the SeaBotix ROV in 2011.

[167] ODIM Brooke Ocean Technology, "ELSS Pod Posting – Submarine Pod Posting System for the Canadian Navy," assessed 23 February 2013, http://www.brooke-ocean.com/elss-01.html.

waits for the arrival of a submarine rescue capability. Like most NATO navies, the RCN relies on the USN's Deep Submergence Rescue Vehicle or the NATO Submarine Rescues System to enable the rescue of the crew of bottomed submarines. The ROV capability now enables the RCN to deploy the life support pods to a submarine that is deeper than diver capabilities. Most recently, the RCN deployed its BOIV and SeaBotix ROVs to assist the RCMP in underwater security during Operation Podium in 2010.

Notwithstanding the successes that the RCN's ROV fleet have achieved, there still remain several challenges that must be overcome in order for them to become a conventional capability within the RCN. The first challenge is that the core ROV operational expertise within the RCN resides almost solely with the Clearance Diver occupation. At first glance this appears to be the best option, but the Clearance Diver branch is also one of the smallest occupations within the Navy. Coupled with the fact that their other specialist capabilities, such as: EOD; CIED; underwater salvage; and NMCM diving are always in high demand, leading to an inability to maintain their operator currency on the systems. In order to mitigate this, the RCN has started to train selected personnel of the Kingston Class ships and shore establishments to augment the diver ROV operators. Another factor that may resolve the operator shortage is that since the combat operations in Afghanistan have completed, the requirement to support the CIED task has diminished. This should allow the diving community to re-focus their personnel resources back onto to their core naval tasks, such as ROV operations.

The second challenge is that of maintaining the ROVs in an operational condition. The main rationale behind replacing the manned submersible capability was that the Navy could reduce man-power; with the expectation that ROVs would be easier and cheaper to maintain. Although the Navy was able to achieve some personnel savings, and was able to reduce cost by no longer requiring the stringent safety certification process required for manned submersibles. The Navy under estimated the technical complexity of the new ROVs and its internal ability to maintain their operational status. One of the reasons for this inability is due to the inherent uniqueness of the ROV systems which are designed to operate under very dangerous conditions, such as extreme pressures. These systems are not comparable with most naval electronics systems that naval technicians are trained to maintain. As a result of this, the DSIS is currently in long-term non-operational status. In order to rectify this situation, the RCN now realizes that it requires commercial assistance in maintaining its ROVs, and is in the process of setting up in-service support contracts, in which the maintenance of the ROVs will be conducted by a commercial ROV contractor.

Notwithstanding the challenges that have been experienced with ROVs, the RCN remains committed to its seabed intervention tasks, as demonstrated by the 2012 contract award to acquire four more SeaBotix ROVs to enhance the RCN's capability.[168] As well, the RCN's RMDS Project, which is currently in the project definition phase, intends to acquire a specific NMCM ROV capability. Within the project scope the RMDS project aims to acquire a mine inspection and disposal capability. It is expected that this capability will consist of expendable mine disposal vehicles, similar to systems shown in Figure 27. These mission-specific ROVs are light weight, low cost, and expendable. They are expendable, in that they are designed to locate a previously identified sea mine with its onboard sonar; then an operator manoeuvres the vehicle up to the sea mine and visually identifies it using the onboard underwater low-light video camera; and finally, the identified sea mine can be destroyed by firing the shaped charge from within the body into the sea mine.[169] In conjunction with the expendable combat vehicle, the RMDS project will also acquire the training and inspection variants.

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[168] Department of National Defence, "News Release: Ministers MacKay and Ambrose Announce Support for Remote Operated Vehicles," accessed on 24 February 2013, http://www.dnd.ca/site/news-nouvelles/news-nouvelles-eng.asp?id=4248.

[169] Some consider this similar to the arming of UAVs, but these systems were specifically designed to counter-mine sea mines or other ordinance on the seabed. A task previously conducted by Clearance Divers. As stated above, this is very similar to tasks conducted presently by UGVs in the land environment.

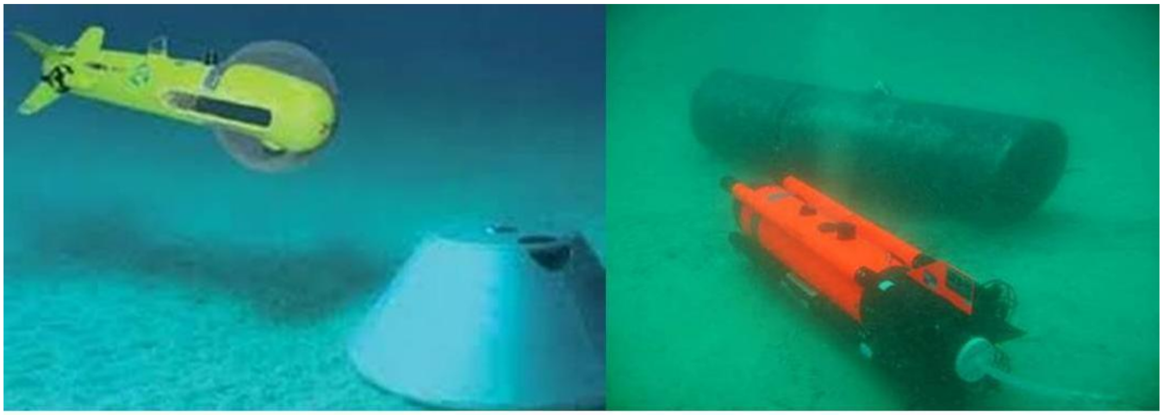

Figure 27 – Expendable Mine Disposal Systems. ECA K-STER MINEKILLER (left) and Atlas SEAFOX Mine Disposal Vehicle (right).

Source: Jane's Online.[170,171]

By providing these NMCM specific ROVs, it will significantly enhance the RCN's ability to conduct the last two steps in the NMCM sequence, sea mine identification and disposal.[172] Traditionally one of the most dangerous tasks conducted by the Navy's Clearance Divers, the NMCM ROVs will be able to work at greater depths, for longer periods of time and will make the task of removing the sea mine threat much safer. Notwithstanding the capability of the NMCM ROVs, Clearance Divers will still be required, in order to render safe suspected sea mines for exploitation and intelligence purposes.

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[170] Jane's Online, "Weapons: Naval, K-STER," *accessed 23 February 2013, https://janes.ihs.com/CustomPages/Janes/DisplayPage.aspx?DocType=Reference&ItemId=+++1394123&Pubabbrev=JUWT.*

[171] Jane's Online, "Jane's Unmanned Maritime Vehicles and Systems, SEAFOX C and I Models," accessed 23 February 2013, https://janes.ihs.com/CustomPages/Janes/DisplayPage.aspx?DocType=Reference&ItemId=+++1323757&Pubabbrev=JUMV.

[172] The NMCM sequence was describe in Chapter Three.

AUTONOMOUS UNDERWATER VEHICLES

RCN interest into UUVs commenced as soon as the 1987 White Paper, directed that the RCN re-acquire an NMCM capability.[173] In support of this direction, the RCN commenced options analysis studies to determine the best options to execute this direction. Early on in the process, it quickly became apparent that regardless of the political direction, there was no appetite or budget allocation to commence a project to build a NMCM force comprised of dedicated NMCM vessels. In order to attain efficiencies, and to ensure that the Navy remained within its assigned capital budget allocation, the new NMCM requirement was inserted into the scope of the ongoing Maritime Coastal Defence Vessel (MCDV) Project. The objectives of the MCDV project, was to deliver: twelve Kingston Class ships; Mechanical Minesweeping Systems; four Route Survey Systems with associated shore-based data analysis systems; a Mine Inspection ROV; and an off-board Remote NMCM System. Unfortunately, early in the MCDV project, it was quickly realized that the unmanned system technology was still at a relatively immature state and was unproved operationally. Therefore in order to avoid a high risk procurement, the Remote NMCM capability was removed from the MCDV Project scope, with the intention to deliver it when the technology could be proven.

[173] In regards to ROVs, it is their NMCM applications and utility that is being referred to, as the RCN has been using ROVs to conduct numerous other missions in support of its underwater intervention tasks.

As unmanned technology continued to mature throughout the 1990s into the early 2000s, the RCN closely monitored its developments, including work being conducted in other allied navies. With the assistance of DRDC, it commenced a technology risk reduction programme culminating with the RMS - Technology Demonstrator Project (TDP).[174] The RMS-TDP was conducted from 2002 to 2007, and successfully demonstrated the maturity and applicability of the unmanned technology necessary to acquire a RMS.[175] Based on this the RCN re-commenced a dedicated programme to acquire a remote NMCM capability to be delivered through the RMDS Project. Notwithstanding the overall success of the RMS-TDP, there were numerous technical challenges and risks associated with the prototype.[176] As a result of these technical challenges, the RMDS Project Team conducted a comparative analysis between the DORADO USV and available AUV systems to determine which system had less technical risk. Consequently, it was determined that the RMDS project would pursue the acquisition of AUVs in order to satisfy the RCN's NMCM operational requirements.[177]

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[174] A more detailed description of the RMS-TDP is given in the previous chapter.

[175] Due to the success of the RMS-TDP, the prototype system, the DORADO Minehunting USV was brought into interim operational service in order to continue the system evaluation and conduct further remote NMCM tactical development. The system was kept in interim operational status until the end of Operation Podium, where the system contributed to the underwater security picture.

[176] The technical risks and challenges of the DORADO USV, were discussed in Chapter Four, but are related to the prototypes overall weight and size. This affected the systems overall deployability status.

[177] Royal Canadian Navy, *RMDS SOR V2.0 C.001334. Statement of Operational Requirement: Remote Minehunting and Disposal System* (Ottawa: RCN, March 2012), 7.

AUV Development History

Unlike ROVs and other unmanned systems, the development of AUVs has taken a much longer road. Work on AUVs commenced in the "1960's with R&D vehicles such as the Self-Propelled Underwater Research Vehicle (SPURV), developed at the Applied Physics Laboratory of the University of Washington."[178] The SPURV was soon followed by developmental vehicles from academic and research institutions, such as the Woods Hole Oceanographic Institution, MIT's Robotics Laboratory, Shirshov Institute of Oceanology, Office of Naval Research, and the University of Southampton. Initially referred to as untethered robots or smart unmanned free swimming submersibles; early AUV developments were driven by the desire to overcome limitations that were being experienced with ROVs due to the tether that caused drag and limited the distance from the command ship, onboard power supplies and launch and recovery systems.

Unfortunately, all of the initial AUV designs were either too big, ineffective, or very expensive; nor did they show any promise with regards to overcoming the limitations that were being experienced with ROVs. In addition, the early vehicles did not possess any onboard intelligence, as the vehicles were controlled by underwater

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[178] Christopher von Alt, "Autonomous Underwater Vehicles," *Prepared for the Autonomous Underwater Lagrangian Platforms and Sensors Workshop* (22-24 March 2003), 2.

acoustic data links.[179] These acoustic data links proved to be more of a limitation than the ROVs physical tether, in that they drained onboard power supplies, were vulnerable to acoustic interference, and was subject to significant time delays. In the meantime, ROV technology was rapidly gaining in maturity, and by the early 1980's, AUV development had stalled still in relative infancy. Unlike ROVs, which has the features such as a human brain (the pilot), which is connected by a nervous system (the tether) and possesses muscle (electric or hydraulic power); in comparison, AUVs are required to carry these human attributes with them.[180] Unfortunately, this design requirement proved unattainable for 1980s computer processing, and battery technologies.[181] Although the early AUVs proved to be of limited value, they did highlight the requirement for the following five future AUV design features: increased energy storage; increased computational power; precise navigation; improved levels of autonomy, and more efficient sensors. Notwithstanding the early challenges and the slower developmental path, by the early 1990s, the computer processing and onboard battery technology had improved exponentially which paved the way for renewed activity and interest in AUV development and awareness. These developments meant that the issue of computer processing (brains) and vehicle endurance (the muscle) could be overcome.

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[179] Steven Shaker, and Alan Wise, *War Without Man, Robots on the Battlefield* (Washington: Pergamon-Braaey's, 1988), 43.

[180] Marine Technology Society, "ROV Categories - Untethered Autonomous Underwater Vehicles (AUVs)," accessed 14 April 2013, http://www.rov.org/rov_category_auvs.cfm.

[181] Robert L. Wernli, *AUV'S - The Maturity of the Technology* (San Diego: SPAWAR, 2000), 1.

As the technology and system development rapidly matured, navies started to see the potential of UUVs and in particular AUVs. In fact initially, most navies that have embraced this technology continue to accept these robust commercial systems right off the shelf, without requiring any further modification. This type of procurement has proved to be cost effective due to not having to require commercial vendors to re-engineer their already robust current systems in order to make them compliant to unique military specifications.

AUV Cost Benefit

It is not the intention of this section to conduct a detailed cost benefit analysis of AUVs. Although as demonstrated in Figure 29, it is easy to see the potential cost savings these systems can provide. Subsequently, as the RCN is attempting to acquire a credible NMCM capability, it is considered that AUVs can significantly contribute to increased operational effectiveness and reduced risk to its personnel and ships. Furthermore they represent a potential to reduce procurement and long term operational costs. The commercial and academic sectors are already realizing the advantages of employing AUVs in various underwater activities.

As discussed earlier, ROVs with their greater depth and endurance capabilities have replaced divers in many situations. Since the introduction of AUVs into the commercial and academic sectors, they have demonstrated the ability to conduct deep underwater surveys that are quicker and more cost effective than traditional survey ship operations. For example, C&C Technologies, an underwater survey and mapping company, recently conducted a cost analysis trial, comparing their standard deep-tow survey method with that of AUVs. Conducting simultaneous missions in the Gulf of Mexico and off the coast of West Africa, C&C determined that AUVs conducted operations faster, were more manoeuvrable, had better positional accuracy, and reduced support ship times. In the end, the company estimated that AUVs could achieve a cost savings of between 39 to 59 percent.[182] Based on this, the company has invested in AUVs as part of their line of operations. Its first AUV, a Kongsberg Hugin AUV has since completed over 200,000 km of survey work.

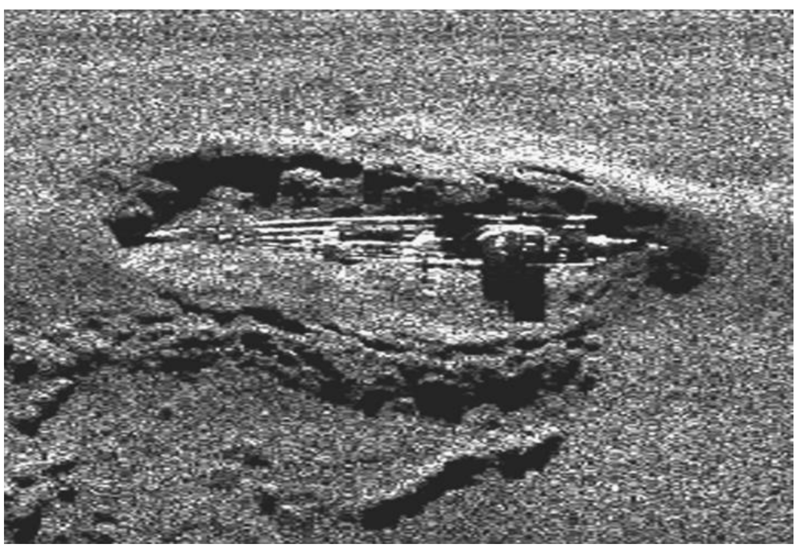

Figure 28 – AUV Sonar Image. A Side Scan Sonar image of the World War II U-166, located in the Gulf of Mexico, in 1,525 m of water. The U-Boat was located during a pipeline survey being conducted for BP and Shell International Exploration and Production. It was positively identified later by a ROV.

Source: C&C Technologies.[183]

[182] C & C Technologies Inc, "AUV Experiences: Discoveries and Lessons Learned," accessed 15 April 2013, http://www.cctechnol.com/uploads/UUVS_AUVExperiences.pdf.

[183] *Ibid.*

Research also suggests that AUVs can also offer cost advantages to naval operations. As a result of successful applications of AUVs in the commercial and academic sectors, many navies, primarily led by the USN, are investigating how to fully integrate AUVs into their inventories. In order to accomplish this, the USN has implemented a UUV Master Plan, where it identifies missions, capabilities, performance levels, classifications, and technology requirements.[184]

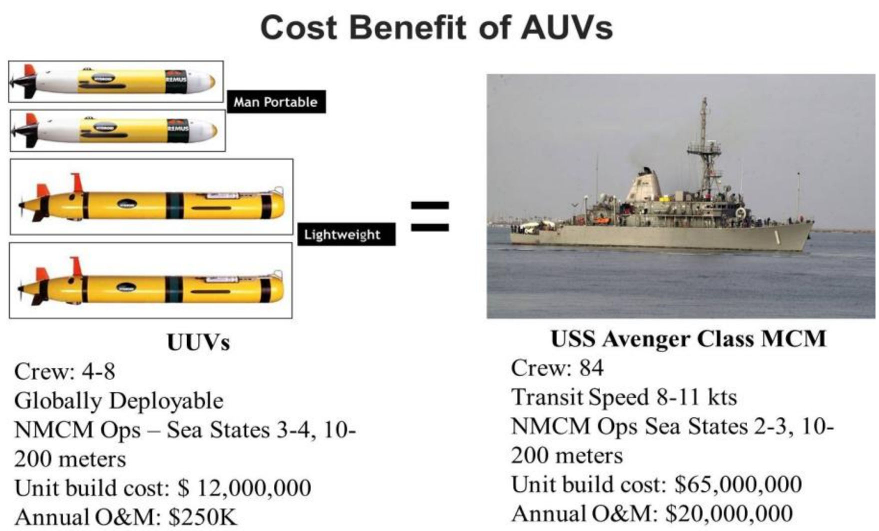

Figure 29 – Cost Benefit of AUVs. A basic cost analysis of employing a suite of AUVs versus a traditional NMCM vessel. Costing data should be treated as substantive estimates, but are sufficiently accurate enough to demonstrate the relative cost and operational benefits.

Source: Various.[185]

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[184] Program Executive Office, *The Navy's Unmanned Undersea Vehicle (UUV) Master Plan*, (Washington: Department of the Navy, 09 November 2004), xviii.

[185] Information for the image was gathered from various internet sites. The cost estimate for the USS Avenger was taken from an average of various NMCMV Programs over the last 20 years. The AUV

In order to achieve budgetary efficiencies, many navies are tapping into the COTS AUV market, to acquire AUVs that were developed as a result of commercial and academic activities. Consequently, if the RCN intends to capitalize on the potential cost savings that can be realized by procuring COTS systems, it first must avoid the desire to have a system developer engineer a new system or re-engineer an existing AUV design to meet Canadian specific requirements. Secondly, that the RCN maintain its current intention to acquire systems that have attained a high NATO technical readiness level, thus avoiding the issues associated with acquiring a developmental system, which comes with extra costs due to the requirement to conduct spiral R&D to bring the system to an operational status. These strategies will allow the RCN to gain efficiencies by partnering with allied nations in order to achieve collective benefits by having common training and operational tactics, thus increasing interoperability. This is also in line with the NATO Smart Defence Initiative, which "encourages Allies to cooperate in developing, acquiring and maintaining military capabilities."[186] Conducting an AUV procurement using the Smart Defence Initiative will allow nations to reduce supply chains, which may improve availability, as well as offering a cost-effective procurement path by exploiting the benefits of scale.

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cost estimate was the cost of a recent RN acquisition that occurred in 2006, which was reported in Robert Button, et al., A Survey of Missions for Unmanned Undersea Vehicles (Santa Monica: RAND Corporation, 2009), 126.

[186] NATO, "Smart Defence," accessed 15 April 2013, http://www.nato.int/cps/en/natolive/78125.htm.

AUV Classifications

Meeting stated operational requirements and minimizing cost are the two major considerations that must be addressed when developing an AUV acquisition program. In articulating its operational AUV requirements, the RCN has stated that any future AUV will be primarily deployed from the Kingston Class vessels. Notwithstanding this requirement the RCN also understands the value in being able to operate AUVs from shore locations, small vessels, and major RCN surface combatants.[187] In order to meet these requirements the RMDS project is intending to deliver a mix of small to medium AUVs, and further defines the overall weight of each AUV type to be no more than 70 and 800 kg respectively.[188] Unfortunately, as the RCN was finalizing its AUV requirements, NATO with heavy assistance from the USN, was defining its own AUV Classification system in order to assist partner nations and industry in defining the AUV military requirement and developing acquisition programs. NATO now defines AUVs in the following four classes:[189]

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[187] Royal Canadian Navy, *RMDS SOR V2.0 C.001334. Statement of Operational Requirement: Remote Minehunting and Disposal System*, (Ottawa: RCN, March 2012), 4.

[188] *Ibid.*, 7, 12-13.

[189] Combined Joint Operations from the Sea Centre of Excellence. *Guidance for developing Maritime Unmanned Systems (MUS) capability* (Norfolk: NATO, 09 July 2012), 7-8.

Man-Portable Class

These include AUVs from 11.33 to 45.35 kg displacement, and are generally about 22.5 centimeters (cm) in diameter. This class is very useful in shallow and confined water spaces, but also limited in the type of sensors it can carry. They have endurances of 10 to 20 hrs.

Light-Weight Class

These include AUVs that displace up to 226.79 kg, and are usually 32.38 cm in diameter. Their sensor and battery capacities increases 6 to 12 fold over the Man-Portable class and mission endurance is doubled.

Heavy-Weight Class

These include AUVs that displace up to 1360.77 kg and have a diameter of 53.34 cm.[190] These AUVs provide more than double the capability of the Light-Weight Class.

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[190] An original USN design requirement for AUVs was that they has to compatible with the various diameters for submarine external openings, such as torpedo tubes (21 inch or 53.34 cm, standard NATO torpedo diameter).

Large Vehicle Class

This vehicle class was established to take into account future requirements and developments. It is anticipated that future Large AUVs will displace up to 10 metric tonnes. Currently no vehicles in this class exist.

In order for the RCN to proceed with clear requirements and strive to maintain compatibility with its allies, it is recommended that future revisions to the RMDS Project Statement of Operational Requirements be updated to reflect the established NATO AUV classification system. This will bring the RCN closer to accepted doctrine, which will aid in interoperability and bring Canada in line with the Smart Defence initiative.

Although cost is an initial driver for considering the acquisition of unmanned systems, the RCN must be cognizant that this cost reduction will not be realized overnight. It is assessed that initially, the integration of AUVs into the RCN will result in an increase in personnel and operational cost. This cost increase takes into account costs of acquisition, training, manning and sparing that any new military system comes with. Nevertheless, the RCN will experience an increased capability, as it takes advantage of AUV capabilities through operational use and tactical development. Notwithstanding the initial start-up cost, it is anticipated once final operational capability is achieved; AUVs will increase RCN capability, and eventually decrease personnel and operational costs.

AUV Industry Survey

As part of the research for this paper, an extensive web-based open-source internet survey was conducted using online professional journals and magazines; and vendor brochures. The aim was to determine the current market viability for commercial AUV manufacturers to supply COTS AUVs suitable for naval operations in support of NMCM. AUVs currently being developed by academia were not considered to be COTS systems.

Figure 30 - Various AUV Systems from over 60 manufactures.

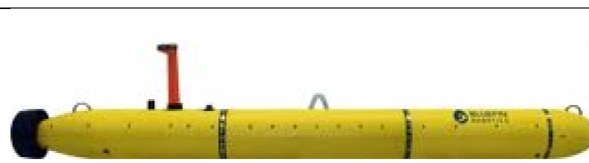
Source: Autonomous Undersea Vehicle Application Center.[191]

[191] Autonomous Undersea Vehicle Application Center, "AUV Manufacturers Collage," accessed 15 April 2013, http://auvac.org/.

Based on the survey, it was determined that currently there are over sixty COTS AUV systems being offered by commercial manufacturers. Notwithstanding the large quantity of systems, the results of this research also determined that there are AUV systems that appear to be more prominent in the military COTS market place. These AUV systems as shown in Table Two, had manufacturers that had significant sales and established manufacturing capability.

Table 2 – Available COTS AUVS.

MAN-PORTABLE	
Hydroid - REMUS 100 **Weight:** 38.5 kg **Length**: 160 cm **Depth Rating:** 100 m **Mission Endurance:** 8-10 hrs **Naval Use:** USN, RAN, RN, RNNZN, RNLN, Belgian, Croatian, Estonian, German, and Swedish navies	
Bluefin Robotics - **BLUEFIN 9** **Weight:** 60.5 kg **Length**: 175 cm **Depth Rating:** 200 m **Mission Endurance:** 12 hrs **Naval Use:** USN	
GAVIA **Weight:** 62 kg **Length**: 180 – 260 cm **Depth Rating:** 500-1000 m **Mission Endurance: 7** hrs **Naval Use:** Danish, Portuguese, Russian, and US	

navies	
Ocean Server – IVER 2 **Weight:** 19 kg **Length**: 130 cm **Depth Rating:** 100 m **Mission Endurance:** 14 hrs **Naval Use:** USN, DRDC	
LIGHT WEIGHT	
Hydroid - REMUS 600 **Weight:** 240 kg **Length:** 3.5 m **Depth Rating:** 600 m **Mission Endurance:** 24 hrs **Naval Use:** USN, RN, and RAN	
Bluefin Robotics- **BLUEFIN 12** **Weight:** 240 kg **Length:** 3.8 m **Depth Rating:** 1500 m **Mission Endurance:** 30 hrs **Naval Use:** USN, and Israeli Defence Force	
HEAVY WEIGHT	
ATLAS Elecktonik – Sea **Otter** **Weight:** 1000 kg **Length:** 3.65 m **Depth Rating:** 600 m **Mission Endurance:** 20 hrs **Naval Use:** German Navy	

Saab – Double Eagle **Weight:** 540 kg **Length:** 2.9 m **Depth Rating:** 500 m **Mission Endurance:** 10+ hrs **Naval Use:** Swedish Navy	
ISE - Explorer **Weight:** 750 - 1250 kg **Length:** 4.5 – 6 m **Depth Rating:** 300-5000 m **Mission Endurance:** 22-44 hrs **Naval Use:** Japanese Coast Guard, DRDC (Canada)	
Kongsberg – Hugin 1000 **Weight:** 1200 kg **Length:** 5.4 m **Depth Rating:** 1000 m **Mission Endurance:** 24 – 74 hrs **Naval Use:** Norwegian and Indian navies	
Bluefin Robotics-BLUEFIN **21** **Weight:** 750 kg **Length:** 5.0 m **Depth Rating:** 4500 m **Mission Endurance:** 25 hrs **Naval Use:** USN	

Source: Autonomous Undersea Vehicle Application Center Database.[192]

[192] Autonomous Undersea Vehicle Application Center, “AUV Database,” accessed 15 April 2013. http://auvac.org/.

The above systems were evaluated as possessing sufficient open source material to support analysis; and were assessed to be *prominent* in the commercial and military COTS marketplaces, as well as being able to be delivered as *turn-key* systems for naval operations. *Prominent* in the marketplace is demonstrated by the manufacturer's demonstrated customer base, proven AUV technical readiness levels, and indicated open architecture designs. The *turn-key* delivery indicates that the manufacturer is able to provide in-service support to their AUV systems and support equipment, at the same time as enabling the purchaser to integrate, and operate the systems. In the course of conducting this research, it was apparent that many AUV manufacturers did not appear to have systems that would be considered mature enough for naval operations. These providers were more suited to supply their systems to academic institutions where invariably the AUVs are significantly modified for specific research activities.

For the RCN, this survey demonstrates that the current AUV market, and its associated technology has advanced significantly over the last 20 years, and is forecasted to continue to evolve rapidly as commercial, academia and many navies fund further AUV developments. Open source data, also suggests that there is a significant increase of AUV systems being introduced to many of the RCN's allied partners. This trend signifies a transition from expensive legacy NMCM systems towards that of AUV technologies. Consequently, as the RCN moves forward with the acquisition of AUVs, it will be doing so in a healthy competitive market that offers mature, robust technology to meet the demands of not only the military, but the commercial and academic sectors.

AUV Key Technologies and Autonomy

Autonomy

Since the start of early development, there has always been considerable effort placed into understanding how to give an AUV a level of intelligence necessary to accomplish assigned tasks. Vehicle autonomy is the key capability which ensures the success of an AUV task; and the requirement for long-term independent operations will be the basis for any future naval missions. In order for AUVs to be considered game changers, they require the capability to travel long distances, sense, evaluate, and evade potential dangers; as well as collect mission data independent of human interaction. Of particular importance is the ability of these systems to adapt intelligently to a changing tactical environment. Future capabilities will also require the ability for an AUV to conduct its own mission at the same time as having the capacity to interact and collaborate with multiple AUVs. These above capabilities will be vital to successful accomplishment of large scale NMCM and other naval missions. Consequently, the USN considers autonomy and vehicle control a major research area for future AUV development, whether military, commercial, or academic in origin.[193]

Notwithstanding the significant effort being put forth regarding autonomy R&D by the USN, DRDC has also been contributing to this research area. Based on this the RCN and DRDC must continue to maintain their close liaison with other allied navies and R&D organizations, such as the NATO Undersea Research Centre and Office of Naval Research. Allied working groups such as NATO and ABCANZ[194] Technical Cooperation Panels will also provide R&D leveraging opportunities. While this R&D is ongoing, in the short-term any acquisition of AUVs must take into account the spiral nature of this research, therefore the RCN must as far as possible ensure that potential AUVs possess open architecture designs that enable upgrades to their inherent autonomy.

Power and Energy

Energy has long been a major consideration due to its effect on the ultimate performance of AUVs and their future missions. Despite significant advances in onboard battery and fuel cell technologies; mission endurance still remains an issue.

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[193] Program Executive Office, *The Navy's Unmanned Undersea Vehicle (UUV) Master Plan* (Washington: Department of the Navy, 09 November 2004), 57-58.

[194] ABCANZ stands for America, Britain, Canada, Australia, and New Zealand. This group is often referred to as the Five Eyes Community. It represents a multilateral treaty and represents a level of military clearance/restriction/classification to enable a degree of commonality in tactics and procedures that will assists in the seamless integration of forces.

During a recent survey of AUV developers, it indicated that development of future propulsion power and energy solutions continue to remain a long-term challenge.[195] Notwithstanding these ongoing developments, the following two AUV design considerations will continue to affect AUV performance. First, AUV size affects sensor and battery capacities. Secondly, the sensor types and configuration have an impact. Basically the more electronics that get integrated into a vehicle, the larger the drain on the existing power supply, which in the end affects mission endurance.

The selection of a power source is a significant design factor for any AUV, and it should be selected early in the design process. The power source is contingent on the overall size and purpose of the vehicle. For Man-Portable to Light-Weight AUVs, cheaper primary lithium and lithium ion batteries should be considered. As the operational depth increases, lithium ion batteries get the edge, due to their inherent pressure tolerance. For the Heavy-Weight AUVs, which are intended for extreme deep operations, more expensive but pressure resilient semi-fuel or hydrogen/oxygen fuel cells are advantageous due to their ability to use the fuel cell's stored gas to assist in the vehicles buoyancy.[196]

As the RMDS project moves through its definition phase, it will be incumbent upon the project to remain cognizant of commercial developments in energy-storage

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[195] Robert Button, et al., *A Survey of Missions for Unmanned Undersea Vehicles* (Santa Monica: RAND Corporation, 2009), 49.

[196] Øistein Hasvold, et al., "Power sources for Autonomous Underwater Vehicles," *Journal of Power Sources* 162, no.22 (November 2006): 935.

technologies. Lithium-ion and fuel cell batteries provide significant advantages over older technologies due to their “high energy densities which provide significant benefits in weight, size, energy densities and extended mission durations.”[197] However, these batteries have inherent risks as their energy densities increase. To assure that the risks associated with these batteries are characterized and accepted appropriately, the RCN will be required to institute AUV battery safety protocols similar to the USN's Lithium Battery Safety Program.[198]

Navigation and Sensors

AUV sensors and navigation systems are extremely mature. This is as a result of ongoing research in compacting existing systems to be able to fit into some of the smaller AUV bodies. Their also has been significant work done in minimizing the power consumption of these systems in order to enhance AUV endurance.

The primary navigation systems currently in use in AUVs are doppler velocity logs to measure speed; GPS for initial position and updates while surfaced; and inertial navigation systems to navigate the vehicle while submerged. These three

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[197] N. Raman, David Mall, Kamen Nechev, and Mike Saft, “Recent Advancements in Lithium Ion High Energy Batteries for Undersea Vehicle Applications,” *Underwater Intervention 2005*, accessed on 18 April 2013, http://www.underwaterintervention.com/TechnicalProgramAbstracts.htm.

[198] Julie Banner, and Clinton Winchester, *Lithium Battery Safety in Support of Operational Fielding of Unmanned Underwater Vehicles (West Bethesda: Naval Surface Warfare Center*, *22 August 2011), 1.*

systems are normally integrated in order to enhance the positional accuracy of the vehicle. Notwithstanding the maturity of these systems, there are concerns from the military sector regarding GPS jamming in a non-permissive environment. Although not of great concern to the civilian AUV market, the risk of GPS jamming does have some military planners looking at future AUV navigation requirements.

In regards to sensors, there is significant consensus that COTS oceanographic sensors such as side scan, synthetic aperture, and bathymetric sonars that are currently available for AUVs are meeting most of the NMCM requirements. In addition, the USN has been looking into improved sensors and capabilities beyond that of existing COTS sensors; but for the most part these systems still reside within the classified realm.

Needless to say, from an RCN perspective, in regards to navigation and sensor systems, the COTS marketplace should be able to meet or exceed the RCNs initial operational requirements. Again, any future AUV acquisition should place a high emphasis on an open architecture design philosophy.

AUV Roles

The USN has conducted significant work in articulating its intentions regarding the use of AUVs to support NMCM operations. In addition, it has also identified other naval missions that can be supported by AUVs in its 2004 UUV

Master Plan.[199] The Master Plan defines current and future AUV capabilities and missions and ensures that they are consistent with Sea Power 21,[200] by establishing levels of performance for the USN's UUV programme. It acknowledges the current maturity of the AUV NMCM programme and also identifies and prioritizes the following nine AUV capability areas: ISR; NMCM; ASW; Inspection/Identification; Oceanography; Communication/Navigation Network Node; Payload Delivery, Information Operations; and Time Critical Strike missions. In identifying these capability areas, it allows for efficient prioritization of R&D and procurement investments. In addition the UUV Master Plan is also complimentary to the USN's documents on USVs and UAVs, as well; it also feeds into the US Military's Unmanned Systems Integrated Roadmap, which provides a DoD and Joint focus.

At present, the RCN is only planning to acquire AUVs to support the NMCM capability requirement. Notwithstanding this, the RCN has acknowledged the potential value in unmanned systems to support future naval operations. Unfortunately, the RCN does not have the force development resources available in order to identify additional future AUV roles. It should also be wary of trying to induce mission creep into the current RMDS project scope, in order to avoid further delays in the acquisition process. This situation might be able to be resolved at the

[199] The UUV Master Plan was released in 2012, but currently it is classified and not releasable.

[200] Sea Power 21 is the USN, strategic transformation plan in an effort to make the Navy more flexible and more agile to effectively meet the threat of the 21st century. It is the USNs equivalent to the RCN’s Leadmark document.

CAF Joint level, where the CAF's Chief of Force Development could put resources towards the development of an integrated unmanned systems joint document.

Personnel and Training

The direction in the 1987 White Paper to assign NMCM primarily to clearance divers and members of the Naval Reserve was seen as a positive step in introducing the capability back into the RCN.[201] Outside of manning the Kingston Class, there are a number of Naval Reserve personnel that have become highly skilled in NMCM and Route Survey operations. These individuals support the personnel within the Naval Clearance Diving Branch, who also possess significant NMCM skills and expertise. Notwithstanding this resident NMCM expertise within the RCN, the pool remains relatively small and in a constant state of flux.[202] In addition, one of the constraints being place on the RMDS project is that the project "will not require an increase to the current RCN personnel establishment."[203] The current expectation is that any future acquisition of AUVs will draw its operators and maintainers from the current establishment of the Kingston Class ships, Fleet Diving Units, and personnel assigned to conduct Route survey.

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[201] Department of National Defence, Leadmark: The Navy's Strategy for 2020 (Ottawa: DND, 2001), 115.

[202] This state of flux is as a result of the inherent nature of employing reserves, as well as the operational tempo that has been maintained by the Clearance Diving Branch due to CIED commitments in Afghanistan.

[203] Royal Canadian Navy, *RMDS SOR V2.0 C.001334. Statement of Operational Requirement: Remote Minehunting and Disposal System* (Ottawa: RCN, March 2012), 16.

Additionally, with the introduction of AUVs and ROVs to the current NMCM inventory, it is anticipated that this increase, combined with their expected complexity will incur a corresponding surge in demand on existing personnel resources currently allocated to NMCM operations, policy and engineering staffs. Based on this it is recommended that the RCN remain cognizant of the personnel implications as the RMDS project progresses from the definition to the implementation phase. As well, it is also recommended that it investigate an increase in the NMCM establishment from its current resources in order to ensure that highly trained MCM specialists are available to operate the new NMCM systems.

Further, in order to bring the NMCM capability into RCN fleet operations as a whole, progressively more advanced NMCM training was developed for naval officers and non-commissioned members of the Clearance Diving Branch, the Naval Reserve, and selected regular force personnel assigned to support the Kingston Class ships. The result was the establishment of a naval Fleet School in Quebec City, as the lead agency for NMCM training in the RCN. From its initial start in 1992, the school has transitioned from offering NMCM equipment specific training, to internationally recognized Basic and Intermediate NMCM courses.[204] Notwithstanding the current dedicated NMCM training given to Clearance Divers and selected Naval Reservist; currently there is no dedicated NMCM training given to general warfare officers or

[204] The RCN's Basic and Intermediate NMCM courses have been accredited by EUGERMIN, the Dutch-Netherlands Mine Warfare School and NATO NMCM Centre of Excellence.

sailors within the RCN.[205] As a result there still remains a generally low appreciation of the sea mine threat and NMCM amongst the majority of the RCN

Legal

There has been significant debates and news coverage regarding the legal and ethical use of unmanned systems. The majority of these debates can be attributed primarily to the operational use of UAVs and UCAVs, and revolve around legal issues regarding personal privacy and drone strikes. In regards to the operational use of AUVs, research indicates that the legal and ethical issues affecting UAVs and UCAVs are not pertinent to AUVs. This is mainly as a result of the way AUVs have developed and the environment they work in. AUVs were designed to allow humans access to the undersea environment, which is inherently dangerous. Hence, they have significantly reduced the risk to humans working in the military, commercial, and academic sectors. Current and future military applications of AUVs also don't indicate any significant intent to weaponize these systems. Consequently there exists no real ethical concern in the short to medium horizon in regards to the employment of AUVs.

There also remains a significant concern regarding existing international maritime law regarding the employment of AUVs, their status as vessels, and

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[205] In some RCN warfare courses, NMCM and sea mines are covered at a very general level.

maritime passage rights. It has been assessed that existing legislation is ambiguous at best, and this may pose restrictions on the lawful and legitimate exploitation of AUV capabilities. The main issue revolves around whether an AUV is considered a Vessel, as define by the International Collision Regulations, which defines a vessel as "every description of water craft, including non-displacement craft and seaplanes, used or capable of being used as a means of transportation on water."[206] To date there has been no consensus on whether an AUV should be included or interpreted as being a vessel. This lack of legal status is also recognized in the 2009 RAND Corporation report entitled, A *Survey of Missions for Unmanned Undersea Vehicles;* where it states that "legal issues are not explicitly addressed in the USN's 2004 UUV Master Plan."[207] The report also goes on to recommend that all future UUV Master Plans and Roadmaps consider legal issues.[208,209]

Regardless of the current legal and ethical status of AUVs with their applications in naval operations; the CAF, as with every new weapons system, will conduct its own legal review, with specific emphasis on the systems application within the *Laws of Armed Conflict (LOAC)*. Consequently, any lack of legal direction should not dissuade the RCN from pursuing the acquisition of AUVs, as there exists a

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[206] International Maritime Organization, International Conference on Revision of the International Regulations for Preventing Collisions at Sea 1972 (London: IMO, 1974), 37.

[207] Program Executive Office, *The Navy's Unmanned Undersea Vehicle (UUV) Master Plan* (Washington: Department of the Navy, 09 November 2004), 104.

[208] *Ibid.*, 12.

[209] It should be noted that since the 2009 RAND report, the USN released the latest version of the UUV Master Plan. Unfortunately the 2012 UUV Master Plan remains classified, and not available, therefore it is unknown if a legal issues section was added.

window of opportunity for Canada to collaborate internationally in order to create and shape the way AUVs are viewed under international maritime law as well as the LOAC.

CHAPTER SEVEN

CONCLUSION

The questions remain; are the RCN's current expectations and intentions regarding NMCM and AUVs achievable; and will they enable a new paradigm in the RCN? Despite having a development history of over 50 years; AUVs have developed at a slower pace than other unmanned systems. Consequently, the insertion of AUV systems into naval operations, in comparison with UAVs and UGVs, remains relatively immature and ill understood. This lack of understanding can be demonstrated by the large inconsistencies in unmanned systems terminology and classification systems. This, in some cases, further contributes to the confusion that is often presented in unmanned systems related discussions. Additionally, history suggests that unmanned systems have yet to resolve human nature's reluctance to trust machines and allow them parity with traditional manned systems. Unfortunately, these issues highlight the fact that AUVs are still considered novel technologies, which have hindered their acceptance within the underwater battle-space. Notwithstanding these perceptions, the increasing use of AUVs within the commercial, and academic sectors; and acceptance in some navies, are rapidly changing the overall perception of AUV capabilities and their potential amongst many navies, the RCN included. Therefore, it can be concluded that regardless of the significant developments in AUV capability; considerable education, as well as technological, doctrinal, and tactical development will be required before AUVs are fully capable and accepted into traditional naval warfare roles.

Just as important as recognizing their limitations, the benefits of AUVs must be equally recognized. In the civilian context, it has been demonstrated that AUVs offer improved endurance; cost savings; and reduce risks to personnel in the harsh underwater environment. Based on the civilian successes, there is an increasing awareness that these advantages can be realized in the naval environment. Notwithstanding the fact that numerous Man-Portable AUVs were used successfully in support of NMCM operations during Operation Iraqi Freedom; the naval utility of AUVs is far from realized; mainly due to rapid technological advances and ongoing debates regarding their full potential to counter the sea mine threat as compared to traditional manned NMCM platforms. Therefore, the introduction of AUVs into the RCN necessitates a thorough understanding of limitations, capabilities, and costs in order to achieve the benefits, as well as avoiding incorrect expectations and misconceptions.

Since its first operational employment, the sea mine has continued to evolve from a mere tactical weapon of limited operational effectiveness to a force multiplier adept at influencing the operational and strategic naval battle-space. Unfortunately, the trend in past conflicts, finds most navies inadequately prepared to face a sea mine threat at the beginning of a conflict. This disinterested mind-set towards the sea mine and NMCM was demonstrated during the First Gulf War, where the coalition naval forces lost control of the sea to the sea mine. This forced a major attitude shift amongst many navies, where planners stopped viewing sea mines and NMCM from the tactical point of view and realized that they could have significant implications at the strategic and operational levels of war. Consequently, there has been a renewed emphasis by most western navies to invest in capabilities to defeat the sea mine threat. For as history has continually demonstrated; the question is not, *"if sea mines will be used in future conflicts*, but simply a *matter of when."*[210]

This paper has highlighted several of the issues regarding AUVs and their employability; particularly in a RCN context. For the RCN, which is intending to acquire numerous AUV and ROV systems through the RMDS project, a keen understanding of the implications in doing so ought to have high importance. While it is expected that project staff officers possess a sound understanding of the issues that have been discussed in this paper, spreading such an understanding throughout the RCN, the CAF and the political leadership will be crucial to the project's success. Operational Commanders; and the Commanders of the RCN, RCAF and Canadian Army will all require common understanding of what they should expect from not only the RMDS AUVs, but the true potential of unmanned systems in order to inform their decisions regarding capabilities, force structure, personnel, and readiness postures and funding. In other words, their expectations must be kept realistic.

AUVs have matured sufficiently to prove their value not only within the modern naval battle-space, but in the harsh underwater commercial market; and their presence is projected to increase over time. Consequently, it will be incumbent on the RCN to continue to explore their benefits as they pertain to NMCM and potential future naval roles. Notwithstanding their game changing potential, it must be remembered that the sea mine remains an elusive naval weapon. Therefore, the ability

[210] Gregory Cornish, "US Naval Mine Warfare Strategy: Analysis of the Way Ahead" (US Army War College Strategy Research Project, 2003), 24.

and employment of AUVs should be approached with a definite cautious optimism. The RCN should also remember that it has been directed to acquire a "limited, but credible NMCM capability."[211] Consequently, it will never be able to afford the *Cadillac Solution*, nor will it be able to acquire all the systems it would like. Therefore it must remembered, that AUVs are *just one tool in the toolbox*, and showing up with just one tool will quickly expose limitations and vulnerabilities; but by insisting on allied *interoperability*, and on *open architecture* designs, will allow for system capability growth, and keep the RCN NMCM capability in charted waters.

Based on historical trends, the RCN in the execution of its assigned roles in domestic and international waters, will continue to deploy to areas where sea mine threats exist. Consequently, it will be required to understand the sea mine threat and must be prepared to defend itself against this threat from adversary nations or non-state groups conducting irregular warfare. Therefore, the RCN must retain and continue to build a capable NMCM capability. Its current intention, which is supported by the CFDS, of acquiring AUVs and ROVs to introduce a remote NMCM capability is sound. It is assessed that procurement of these systems offer the RCN the most cost effective way to re-introduce NMCM back into the RCN. Notwithstanding the current level of RCN support for NMCM; achieving the long term vision as stated in the RCN's NMCM Concept, will require continued commitment by the Government, the CAF, and the RCN leadership. Without this support, the NMCM capability will be at risk to quickly fall prey to the influences of the *Vicious NMCM Cycle*. Notwithstanding, the significant progress and level of effort that is being made

[211] Department of National Defence. *Leadmark: The Navy's Strategy for 2020* (Ottawa: DND, 2001), 155.

to rectify the RCN's NMCM capability deficiencies, this optimism should be tempered with the fact that the Canadian government is in the midst of a deficit reduction programme.

The successful acquisition of AUVs into the RCN will significantly increase its ability to conduct NMCM; contribute to future allied NMCM efforts; and assist in maintaining sea control. As with any unmanned system, their acceptance from novel technology to conventional capability will bring the RCN into a new paradigm. If the RMDS project delivers as planned, and the RCN remains cognizant of the challenges of introducing a new capability into the Navy, then it should be ready to enter the new paradigm. At the end of the day, there will be a requirement to maintain a firm hand on the helm in order for the RCN to maintain track in order not to fall back into the traditional cycle of neglect.

LIST OF ABBREVIATIONS

ABCANZ	America, Britain, Canada, Australia, and New Zealand
ASW	Anti-Submarine Warfare
AUV	Autonomous Underwater Vehicle
AUVSI	Autonomous Unmanned Vehicle Systems International
AWNIS	Allied World-Wide Navigation Information System
BOIV	Bottom Object Inspection Vehicle
C2	Command and Control
CFDS	Canada First Defence Strategy
CBRN	Chemical, Biological, Radiological, and Nuclear
CDT	Clearance Diving Teams
CAF	Canadian Armed Forces
CFDS	Canada First Defence Strategy
CIED	Counter Improvised Explosive Device
cm	Centimeters
CONOP	Concept of Operation
COTS	Commercial Off-the-Shelf
DP	Dynamic Positioning
DoD	Department of Defense
DSIS	Deep Seabed Intervention System
EOD	Explosive Ordinance Disposal
GPS	Global Positioning System
GRP	Glass Reinforced Plastic
HALE	High Altitude Long Endurance
HMCS	Her Majesty's Canadian Ship
hrs	Hours
IED	Improvised Explosive Device
IMCA	International Marine Contractors Association
ISR	Intelligence, Surveillance and Reconnaissance
ISTAR	Intelligence, Surveillance, Target Acquisition and Reconnaissance
JUSTAS	Joint UAV Surveillance and Target Acquisition System
kg	Kilogram

km	Kilometer
LOAC	Laws of Armed Conflict
LCS	Littoral Combat Ship
m	Meters
MALE	Medium Altitude, Long Endurance
MCDV	Maritime Coastal Defence Vessel
MILSPEC	Military Specification
MUAV	Micro-UAVs
MUS	Maritime Unmanned System
NATO	North Atlantic Treaty Organization
NCAGS	Naval Coordination and Guidance of Shipping
nm	Nautical Miles
NMCM	Naval Mine Countermeasure
NMCMV	Naval Mine Countermeasure Vessel
OT&E	Operational Testing and Evaluation
R&D	Research and Development
RAN	Royal Australian Navy
RCAF	Royal Canadian Air Force
RCMP	Royal Canadian Mounted Police
RCN	Royal Canadian Navy
RMDS	Remote Minehunting and Disposal System
RMS	Remote Minehunting System
RN	Royal Navy
ROMECS	Remotely Operated Mechanical Explosive Clearance System
ROV	Remotely Operated Vehicle
SAR	Search and Rescue
SLOC	Sea Lines of Communication
SNMCMG1	Standing Mine Countermeasures Group One
SOF	Special Operations Forces
SPMS	Self-Protective Measures
SPURV	Self-Propelled Underwater Research Vehicle
SUBSAR	Submarine Search and Rescue
TAUV	Tactical UAVs
TDP	Technology Demonstrator Project
TRL	Technology Readiness Level
UAV	Unmanned Aerial Vehicle
UCAV	Unmanned Combat Aerial Vehicle

UGV	Unmanned Ground Vehicle
UMV	Unmanned Vehicle
US	United States
USN	United States Navy
USV	Unmanned Surface Vehicle
UUV	Unmanned Underwater Vehicle
VTUAV	Vertical Take-off and Landing UAV

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