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AUTOMATED EXCLUSION: UNMANNED CONCEPTS FOR MARITIME ANTI-ACCESS AND AREA DENIAL

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INTRODUCTION

Establishing control of the sea is not a novel concept in naval warfare, indeed, it is such a fundamental feature of the maritime battlespace that it forms the backbone of the theories of great naval strategists such as Mahan and Corbett.[1] Whilst both agreed that achieving a high degree of sea control is a driving ambition in naval warfare, they had differing views on how to achieve it. Mahan's doctrine centred on the principle of decisive battle to destroy the adversary fleet thus removing the threat of contention at sea.[2] Corbett's more holistic perspective of sea control, whilst not completely eschewing the use of decisive force, focussed on ensuring freedom of manoeuvre in the maritime as part of the state's overall campaign.[3] However, either theorist's form of sea control has become significantly more difficult to achieve in the last century, particularly so in recent decades.[4] Advances in long-range guided weaponry have led to naval strategists moving towards use of the corollary of the sea control concept, that of denying the use of the sea to an adversary.[5] Termed 'Anti-Access / Area-Denial' (A2/AD),[6] this strategy establishes zones of control whereby an adversary will face significant resistance to entry, pre-dominantly of a lethal variety. To date, A2/AD strategies have been extremely manpower intensive to maintain, which costs the establishing state a significant fraction of its deployable forces. Creating an unmanned

[1] Geoffrey Till, 'Who Said What and Why It Matters', in *Seapower*, Fourth (Abingdon: Routledge, 2018); 61–109.

[2] Philip A. Crowl, 'Alfred Thayer Mahan: The Naval Historian', in *Makers of Modern Strategy from Machiavelli to the Nuclear Age*, ed. Peter Paret, Second (Princeton, NJ: Princeton University Press, 1986); 458-459.

[3] Till, 'Who Said What . . .; 84.

[4] Geoffrey Till, 'Command of the Sea and Sea Control', in *Seapower*, Fourth (Abingdon: Routledge, 2018);184-189.

[5] Ian Speller, 'Combat Operations at Sea Sea Control and Sea Denial', in *Understanding Naval Warfare*, 2nd ed. (London: Routledge, 2018); 118.

[6] Mike Gallagher, 'State of (Deterrence by) Denial', *Washington Quarterly* 42, no. 2 (2019); 31.

A2/AD zone, using autonomous underwater vehicles, would remove this burden and also provide options for defence that would not cost the blood of its citizens.[7] Furthermore, it would be of political benefit for the defending state to be able to refuse access to the A2/AD zone without causing casualties on the adversary's side. In conflicts below the threshold of war, inflicting significant casualties on a competitor's forces may escalate the conflict into open warfare. For the weaker protagonists, this is unlikely to be the effect that the state's government aims to achieve. Employing non-lethal A2/AD capability would provide significant diplomatic options for both sides of the conflict. On the defender's side, the state would capitalise internationally on the fact that no casualties had been caused yet a distinct military effect had been achieved. On the adversary's side, whilst having been repulsed by the defender, it will be much simpler politically to de-escalate the situation when there has been no loss of personnel or significant destruction of equipment.

This paper will demonstrate that a synthesis of current research will conceptually enable a feasible unmanned, non-lethal A2/AD system to be constructed for the maritime battlespace. Firstly, the concept of A2/AD, its main proponents and the maritime drivers for an underwater A2/AD system will be examined before reviewing how traditional underwater weapons achieve effect against adversary targets. Pertinent technological developments in Underwater Unmanned Vehicles (UUV) that significantly increase autonomous capability will subsequently be discussed before a further section explores non-lethal options for disabling adversary vessels. A discourse on how UUVs could be weaponised and employed to achieve such disabling effects will be presented ahead of coalescing the preceding sections into a proposed operational

[7] Jeffrey S. Thurnher, 'Means and Method of the Future: Autonomous Systems', in *Targeting: The Challenges of Modern Warfare*, ed. Paul A.l. Ducheine, Michael N. Schmitt, and Frans P.B. Osinga (The Hague: T.M.C. Asser Press, 2016); 195.

concept for an unmanned A2/AD construct. Penultimately, potential countermeasures that could be used by an adversary to attempt to defeat the proposed A2/AD system will be reviewed before a final section discussed some of the legal questions surrounding the use of a fully autonomous A2/AD system.

ANTI-ACCESS / AREA DENIAL

In the current era of global great power competition, military strategic thought has been refocussed away from asymmetric warfare towards peer-on-peer conflict.[8] For the maritime domain, this implies obtaining control of the sea in order to set 'the conditions to allow freedom of action in a particular part of the sea, at a particular time, to the required degree and, if necessary, deny its use to an opponent'.[9] Historically, power projection navies have focussed on the concept of the decisive battle to ensure continuing freedom of action.[10] However, technological advancements (principally in anti-ship missile capabilities) amongst key maritime powers, in particular China, have made freedom of action in contested areas much more difficult to achieve.[11] Instances of decisive sea engagements between peer forces have been highly limited since the end of the Second World War.[12]

Accordingly, significant emphasis has been placed on the concept of A2/AD, which aims to severely constrain the ability of the enemy to effectively utilise the maritime battlespace.[13] The rise to prominence of this doctrine originates from analysis of the extensive defensive system that China has employed to enable it to restrict access

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[8] Yee Kuang Heng, 'The Continuing Resonance of the War as Risk Management Perspective for Understanding Military Interventions', *Contemporary Security Policy* 39, no. 4 (2018); 546.

[9] Development Concepts and Doctrine Centre, *Joint Doctrine Publication 0-10 UK Maritime Power*, Fifth (Swindon: UK Ministry of Defence, 2017): 42.

[10] *Ibid*., 42.

[11] Stephen Biddle and Ivan Oelrich, 'Future Warfare in the Western Pacific', *International Security* 41, no. 1 (2016); 7. Michael E Hutchens et al., 'Joint Concept for Access and Maneuver in the Global Commons A New Joint Operational Concept', *Joint Force Quarterly* 84, no. 1st Quarter (2017); 135.

[12] Speller, 'Combat Operations at Sea Sea Control and Sea Denial'; 122.

[13] The A2/AD concept also extends to the other warfighting domains but this paper will focus on those that directly affect the maritime battlespace i.e. sea surface, sub-surface, air, cyber and space.

to its surrounding seas (Yellow, East and South China).[14] Applying the Chinese People's Liberation Army's 'non-symmetrical (asymmetrical), non-linear and non-contact war-fighting'[15] principles has resulted in a layered approach, heavily biased towards asymmetric and stand-off weapons such as land-based fixed missile sites, shore-based aircraft and attack submarines.[16] That this strategy is aimed specifically at denying the US access to the Yellow, East and South China Seas has driven a response in strategic policy in the US.[17]

To address the A2/AD challenge, the US has acknowledged that there a need for new US operational doctrine and equipment to defeat an A2/AD system in order to 'preserve freedom of action in the global commons'.[18] However, the more existential threat lies within the projection that the Chinese military will be equal to the US in the near future.[19] In this scenario, Chinese focus will no longer be purely on its near regional interests and they will begin to look at operating further afield to support their national interests.[20] Accordingly, the US dominance of the sea lanes (benevolent as it may be) could be contested by an adversary with numerical superiority. Such concerns have translated into a requirement for the US be able to create an A2/AD exclusion zone of their own.[21] However, this is not just a passive defence measure. Current US strategy guidance has emphasised the need for the US to 'adopt a posture of deterrence

[14] James Johnson, 'Washington's Perceptions and Misperceptions of Beijing's Anti-Access Area-Denial (A2-AD) "Strategy": Implications for Military Escalation Control and Strategic Stability', *Pacific Review* 30, no. 3 (2017); 273–4.

[15] Jingdong Yuan, "Against a Superior Foe : China's Evolving A2/AD Strategy," in *Handbook of US-China Relations*, ed. Andrew T. H. Tan (Cheltenham, UK: Edward Elgar Publishing, 2016); 382.

[16] David W. Kearn, 'Air-Sea Battle and China's Anti-Access and Area Denial Challenge', *Orbis* 58, no. 1 (2014); 132–35.

[17] Sam J Tangredi, 'Anti-Access Strategies in the Pacific: The United States and China', *Parameters* 49, no. 1–2 (2019): 5–20.

[18] Hutchens et al., 'Joint Concept for Access . . .; 135.

[19] Roger Cliff, 'Conclusion', in *China's Military Power: Assessing Current and Future Capabilities* (Cambridge: Cambridge University Press, 2015); 244.

[20] Tangredi, 'Anti-Access Strategies in the Pacific: The United States and China'; 6.

[21] Gallagher, 'State of (Deterrence by) Denial'.

by denial that focuses on denying adversary advances in the first place'.[22] In other words, establishing a denial zone in the path of key adversary targets or lines of advance and not waiting for the adversary to make the first move. Deterrence is achieved by greatly increasing the cost to the adversary of taking an objective and forcing a reassessment of the perceived advantages of continuing to prosecute the target.[23] The US forward defence concept will, by definition, require assets to have global reach and be easily deployable. With no guarantee of host nation support, such US assets will need to predominantly operate from the sea. This global versus local reach is one of the main differentiators between the approaches of the two states; the Chinese solution is heavily focussed on maintaining regional dominance only at this point. However, both approaches are vulnerable to space-based sensors providing targeting information to the adversary and therefore deception and stealth tactics must be employed to neutralise this advantage. In the maritime battlespace, this means employing underwater weapons.

UNDERWATER WEAPONS

From the first attempted attack on a British warship in 1776 by the American 'Turtle' submersible to modern-day nuclear-powered hunter-killer submarines, stealth and deception have been the guiding principles of underwater warfare.[24] Originally developed to attack a superior naval force by a significantly weaker adversary, underwater weapons offer a significant asymmetric threat capability that is extremely hard to defend against.[25]

[22] Gallagher, 'State of (Deterrence by) Denial'; 33.

[23] Elbridge Colby, 'Against the Great Powers: Reflections on Balancing Nuclear and Conventional', *The Strategist* 2, no. 1 (2018); 146.

[24] Dan Van Der Vat, *Stealth at Sea: The History of the Submarine* (Boston: Houghton Mifflin, 1995). 1-10.

[25] David Owen, "Stealth and Silence and Underwater Hunting 1960–1992," in *Anti-Submarine Warfare : An Illustrated History*, First (Barnsley: Pen & Sword Books, 2007); 607.

The torpedo is the main delivery mechanism for targeted underwater attack, although the sea mine has been used to great effect as part of a traditional A2/AD defence system.[26] Conventionally, both types of weapon make use of two methods of causing damage to the target vessel. Firstly, the standard impact method aims to detonate an explosive charge on contact with the target vessel's hull. This method directly damages hull structure through the transmission of shock waves from the explosive impact point.[27] This type of detonation penetrates deeply into hull structure and is generally used to breach submarine pressure hulls such that external water pressure will then destroy the vessel.[28] The second method utilises proximity or influence detonations i.e. exploding at a distance underneath a target. These detonations create a large displacement of the water volume underneath the keel of a ship. The initial phase combines the expanding gas bubble from the explosive and displaced water to lift the centre of the ship upwards, thus significantly stressing the keel. Once the gas dissipates, the ship's centre collapses under gravity into the void created by the gas, whilst the bow and stern are still supported by the sea. This secondary gravitational effect breaks the ship's keel and is highly likely to cause the vessel to sink.[29] Both types of detonation method have been extensively used in designing sea mines and torpedoes since the Second World War.

However, whilst effective at neutralising the adversary vessel, the disadvantage of utilising traditional torpedoes and sea mines is that they will cause mass casualties (owing to the shock wave effects on the human body)[30] and severely damage, if not

[26] Van Der Vat, *Stealth at Sea: The History of the Submarine*. 74-75.

[27] G M Podobriy et al., 'Theorectical Principles of Torpedo Weapons' (Moscow, 1976). 58-60.

[28] Geoff Slocombe, "Lightweight and Heavyweight Torpedo Technology," *Asia Pacific Defence Reporter* Mar (2019); 29.

[29] Gary Lee Sims, 'Damn the Torpedoes: The History of Science and Undersea Warfare in World War II' (Montana State University, 2017). 87.

[30] Christopher G. Blood, 'Analyses of Battle Casualties by Weapon Type Aboard U.S. Navy Warships', *Military Medicine* 157, no. 3 (1992): 124–30, https://doi.org/10.1093/milmed/157.3.124.

sink, the target vessel. These effects may not necessarily achieve the aim of deterrence that the A2/AD strategy was intending to accomplish. It is therefore prudent to identify what alternative delivery mechanisms could be utilised to achieve the desired effect.

AUTONOMOUS UNDERWATER WEAPON TECHNOLOGY

Whilst the Unmanned Aerial Vehicle (UAV) has stolen the limelight from other aspects of drone technology, UUV have developed significant capability in the background.[31] In particular, advances in propulsion, energy storage and underwater target acquisition provide a fertile technology base from which new weapon capability can be synthesised. Furthermore, the development of more sophisticated autonomous control systems has spurred the genesis of the underwater drone 'mothership' – a large UUV that acts as a delivery system for smaller drones or weapons.[32] The Lockheed Martin ORCA is an example of an UUV capable of achieving this effect.[33]

The latest developments in propulsion technology (such as the brushless DC motor) have enabled significant improvements in propulsive efficiency and noise generation whilst also reducing the size and weight of thrusters.[34] When combined with the latest research into UUV form factor design, such as hydrobatics,[35] significant range and manoeuvrability improvements for UUV and autonomous weapon designs are achievable. In addition, the development of wave-powered UUV gliders provide a

[31] Jonathan Gates, 'Is the SSBN Deterrent Vulnerable to Autonomous Drones?', *RUSI Journal* 161, no. 6 (2016); 28.

[32] Jordana Mishory, 'DARPA RELEASES BAA FOR PROGRAM THAT WOULD DELIVER PAYLOADS FROM XLUUV', *Inside the Pentagon* 30, no. 12 (2017): 1–2. Robert W. Button et al., 'A Survey of Missions for Unmanned Undersea Vehicles' (Santa Monica, California, 2009).

[33] The Economist, 'Special Drone Service', *The Economist*, no. 22 June (2019): 69.

[34] Wael Salah, Dahaman Ishak, and Khaleel J. Hammadi, 'Development of PM Brushless DC Motor Drive System for Underwater Applications', in *Proceedings of 2009 IEEE Student Conference on Research and Development* (Serdang, Malaysia: IEEE, 2009); 399–402.

[35] 'Hydrobatics refers to agile maneuvering of underwater vehicles just like aerobatics represents agile maneuvering of aerial vehicles.' Sriharsha Bhat and Ivan Stenius, 'Hydrobatics: A Review of Trends, Challenges and Opportunities for Efficient and Agile Underactuated AUVs', *AUV 2018 - 2018 IEEE/OES Autonomous Underwater Vehicle Workshop, Proceedings*, 2018; 1.

persistent acoustic surveillance capability in A2/AD zones.[36] Both Electromagnetically (EM) and acoustically silent, gliders passively record acoustic information until set parameters are met, whereupon they will surface and transmit their data using an onboard line-of-sight (LoS) communications capability.[37] In this manner, tracking data can be relayed to other friendly assets with minimal detection capability by the adversary.

Energy storage and production for propulsion has historically been a limiting factor of UUV design, greatly diminishing the endurance and, therefore mission breadth, of platforms.[38] Integration of fuel cell technology in a hybrid power construct with traditional lithium-ion batteries has been the focus of significant research in the past ten years.[39] Recent developments from Japan have demonstrated a threefold increase in UUV power capacity using this technology.[40] Harnessing this technology will allow increased mission capability due to enhanced loiter times and longer stand-off ranges. However, this is not the only method of resolving the energy endurance issue. Tethering a UUV to a surface-based, floating solar-cell and communication 'surfboard' provides unlimited energy and endurance, but at the cost of manoeuvrability and speed.[41] Military uses for this technology include long-range, passive detection of maritime targets.

Recent advancements in underwater targeting using a neural network approach have highlighted the power of employing multiple UUVs in parallel (known as

[36] David Downie, 'Future Subsurface Threats' (Toronto: Canadian Forces College, 2019).
[37] Downie.
[38] Alejandro Mendez, Teresa J. Leo, and Miguel A. Herreros, 'Current State of Technology of Fuel Cell Power Systems for Autonomous Underwater Vehicles', *Energies* 7, no. 7 (2014): 4676–93.
[39] Mendez, Leo, and Herreros. 'Current State . . .; 4689.
[40] Satoshi Tsukioka et al., 'The PEM Fuel Cell System for Autonomous Underwater Vehicles', *Marine Technology Society Journal* 39, no. 3 (2005); 62.
[41] Tracy A. Villareal and Cara Wilson, 'A Comparison of the Pac-X Trans-Pacific Wave Glider Data and Satellite Data (MODIS, Aquarius, TRMM and VIIRS)', *PLoS ONE* 9, no. 3 (2014).

swarming) for underwater-based search.[42] This method of inter-UUV cooperation will allow a multi-weapon, multi-target approach to a Fleet engagement. Several weapons can share targeting data during their attack run and autonomously, but collectively, decide the optimal target for each weapon. This would drastically reduce the probability that multiple UUV weapons attack the same vessel and correspondingly increase the overall number of ships that could be hit in a single attack wave. Furthermore, application of swarm architecture is not limited to attack roles.[43] Swarming constructs will enable a highly covert network of passive sensors to be seeded within an A2/AD zone, ensuring a very high intruder detection probability.

Intervention autonomy describes the subset of UUV targeting parameters that provides a system with the ability to align itself spatially in the water relative to a close proximity target.[44] This technology makes use of optical sensors and image processors in the UUV to gauge target separation and orientation.[45] Initially developed for underwater docking operations, implementation of this technology has the capability to accurately guide a UUV weapon to specific points on a ship's hull.

NON-LETHAL MISSION KILL EFFECTS

The purpose of employing non-lethal weapons is to achieve mission kills i.e. remove/disrupt the target vessel's ability to execute a mission without completely destroying it. Predominantly, this will involve either removing the target's ability to manoeuvre freely or remove weapon targeting ability.

[42] Xiang Cao and A. Long Yu, 'Multi-AUV Cooperative Target Search Algorithm in 3-D Underwater Workspace', *Journal of Navigation* 70, no. 6 (2017): 1293–1311.

[43] Dani Goldberg, Sanjeev Seereeram, and Bill Key, 'Swarming Unmanned Underwater Vehicles', *Sea Technology* 58, no. 4 (2017); 32.

[44] N. Vedachalam et al., 'Autonomous Underwater Vehicles - Challenging Developments and Technological Maturity towards Strategic Swarm Robotics Systems', *Marine Georesources and Geotechnology* 37, no. 5 (28 May 2019); 535.

[45] *Ibid*.

Damaging or degrading a surface vessel's ability to manoeuvre has two major effects on a naval Task Force's ability to continue to operate effectively. Firstly, the target vessel itself will be unable to sustain its parent Task Force's speed of advance. This will result in it either being left behind (with a commensurate drop in combat power of the Task Force) or forcing the Task Force slow/stop in place. Secondly, lack of manoeuvrability removes the ship's main defence against being struck by further weapons and highly limits its ability to successfully employ decoys.[46] To prevent loss of the ship, the Task Force would likely expend a further vessel to tow the stricken ship to safety.

The surface warship propulsion system is the main vulnerability that can be exploited to achieve a mobility mission kill. As warships require redundancy in order to operate with battle damage, all larger combat vessels (frigates and larger) have at least

Figure 1- The Arleigh Burke-class guided-missile destroyer USS John S. McCain (DDG 56) sits in Dry Dock 6 onboard Fleet Activities (FLEACT) Yokosuka during an Extended Drydock Selected Restricted Availability, Jan. 26, 2016. (U.S. Navy photo/Peter Burghar)

[46] Dong Xiaoheng et al., 'The Surface Ship Torpedo Defense Simulation System', *2018 3rd IEEE International Conference on Image, Vision and Computing, ICIVC 2018*, 2018; 802–6.

two[47] externally-accessible propeller shaft stern tubes.[48] These are normally arranged in a longitudinally symmetric manner at the stern of the ship (Figure 1 depicts an example arrangement). As these shafts are relatively long in comparison to their diameter, to prevent shaft bending, the weight of the propeller must be braced by the addition of stern tube support struts that attach to the hull of the warship.[49] Loss of the attachment struts would cause catastrophic damage to the propeller shaft during any form of significant manoeuvring or high-speed operation of the shaft.[50]

In addition to mobility mission kill vulnerabilities, surface warships are also susceptible to an equipment mission kill. Combat vessels are highly reliant on sensor and communications equipment that, to enable them to emit/receive electromagnetic (EM) radiation, requires to be left relatively exposed and unarmoured on the main superstructure. This introduces a vulnerability that can be exploited; damage to the sensor equipment used for target acquisition and prosecution renders almost all modern weapon systems combat ineffective. Additionally, modern warships are highly dependent on receiving situational awareness of the battlespace from space-based assets. Inability to receive such data or to report to the fleet command and control element will almost completely remove the asset's ability to continue to operate effectively in the combat zone. However, both types of mission kill are only feasible if the technology exists to deliver this effect.

NON-LETHAL UNDERWATER WEAPONS

[47] It is noted that some larger ships such as the US nuclear-powered aircraft carriers have four propeller shafts.

[48] Malcolm Phillips, 'An Agony of Choice : Propulsion Systems for Modern Warships', *Naval Forces* 28, no. 5 (2007); 90–96.

[49] D Srinivasa Rao et al., 'Determination of Life Cycle and Torsional Vibrational Stress for Marine Propeller Shaft', *Advancement of Mechanical Engineering and Technology* 2, no. 1 (2019): 21–30. P J Gates, *Surface Warships: Volume 3*, First (London: Brassey's Defence Publishers, 1987); 66-67.

[50] Rik Roemen and Jasper Grevink, 'Pont Aven, an Advanced Approach to the Design of a Fast Ferry Shaftline and Bearing Arrangement', *10th International Symposium on Practical Design of Ships and Other Floating Structures, PRADS 2007* 1, no. January 2009 (2007): 162-163.

Conceptually, the most viable option to achieve a mobility mission kill is to embody intervention autonomy technology into a high-speed hydrobatic vehicle body.[51] The hydrobatic form factor will incorporate existing active sonar from a modern lightweight torpedo to approach the target before switching to optical sensors in the weapon's terminal approach phase.[52] This will allow the adversary vessel's stern tube support struts to be identified as a target and the UUV will manoeuvre to intercept. Warheads in such weapons will not need to be large. Impact detonation of a small shaped charge will be sufficient to ensure penetration of the stern tube/support strut whilst also avoiding creation of a gas bubble effect that could unnecessarily damage the ship's hull. Detonation would sever the support and cripple the ship's manoeuvrability yet be extremely unlikely to cause casualties onboard.

An equipment mission kill, however, is theoretically more effective than a mobility kill as it will also remove the target's long-range weapon threat (such as cruise missiles) from the combat zone. Significant research has been focussed on weaponization of High-Power Microwaves (HPM) in recent years.[53] The attraction of HPM is its ability to 'not only . . . penetrate radio front ends, but also for the most minute shielding penetrations throughout the equipment'.[54] However, this weapon would have to be detonated above water as EM radiation is highly attenuated by seawater and signal strength deteriorates as the square of the distance propagated.[55] With the thickness of a warship's hull plating acting as shielding, even a contact detonation would be unlikely to cause significant effect on the adversary vessel's

[51] Bhat and Stenius, 'Hydrobatics: A Review of Trends, Challenges and Opportunities for Efficient and Agile Underactuated AUVs'.

[52] BAE Systems, 'Sting Ray Mod 1 Lightweight Torpedo', 2018.

[53] Bahman Zohuri, 'High-Power Microwave Energy as Weapon', in *Directed-Energy Beam Weapons* (Cham: Springer International Publishing, 2019); 269–308.

[54] *Ibid*.,

[55] Evangelia A. Karagianni, 'Electromagnetic Waves under Sea: Bow-Tie Antenna Design for Wi-Fi Underwater Communications', *Progress In Electromagnetics Research M* 41, no. January (2015); 189–98.

electrical equipment. The solution is to use a pop-up attack i.e. the weapon exits the water at a set speed, ascends by momentum to an effective altitude (approx. 15m above sea level)[56] and detonates in the air. This will maximise the effectiveness and range of the Electromagnetic Pulse (EMP) effect on the target's communication, radar and weapon systems.[57] Given the radius of the potential effect (up to 500m in diameter),[58] one weapon's mission kill zone could encapsulate more than a single vessel. Theoretical designs for air dropped weapons have been produce which would comfortably fit into the form factor of a heavyweight torpedo, allowing space for existing propulsion and guidance systems to be retained.[59] As most warship critical equipment systems are electrically shielded using Faraday cages,[60] an EMP weapon will not cause significant damage, however, by their very nature of operation, communication and sensor equipment cannot be fully shielded and work effectively.[61] It should be noted that there is some risk that a close range EMP could potentially detonate exposed weapons fitted with electronic fuze systems i.e. missiles on launchers or bombs on aircraft. However, modern use of insensitive munitions and safety and armament devices will reduce this to as low as practicable.[62]

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[56] Assuming a planned detonation height of 15m above sea level to clear the hull on most non-capital ships, vertical ascent (i.e. gravitational acceleration acting directly downwards), initial speed of 50 kts and no further propulsion, a weapon would be airborne for 0.67s before detonation.

[57] Zohuri, 'High-Power . . .; 285.

[58] Carlo Kopp, 'An Introduction to the Technical and Operational Aspects of the Electromagnetic Bomb', *Journal of Electronic Defence* Supplement (1997): 36–41.

[59] Jane's Group, 'Spearfish Mod 0', *Jane's Weapons: Naval*, 2019; Zohuri, 'High-Power Microwave Energy as Weapon'. 284.

[60] P. Kulkarni and D. Rajeev, 'Design Considerations for Shielded Compartments in Warships', *Proceedings of the International Conference on Electromagnetic Interference and Compatibility*, 1999; 58–62.

[61] Viren Pereira and G. R. Kunkolienkar, 'EMP (Electro-Magnetic Pulse) Weapon Technology along with EMP Shielding & Detection Methodology', *2013 4th International Conference on Computing, Communications and Networking Technologies, ICCCNT 2013*, 2013; 1–5.

[62] Ian J. Powell, "Insensitive Munitions – Design Principles and Technology Developments," *Propellants, Explosives, Pyrotechnics* 41, no. 3 (2016): 409–13. J F Rouse, *Guided Weapons*, Fourth (London: Brassey's, 2000); 142-143.

A2/AD UUV CONCEPT OF OPERATIONS

To effectively make use of the options that current underwater technology provides, a conceptual operating construct for a layered A2/AD zone is proposed. The outermost layer will consist of a surveillance and detection element, in which a flotilla of solar-powered, surface-tethered, low-profile autonomous drones operate in a swarm configuration. Each of the drones will be capable of passive and active underwater acoustic search and will have LoS radio communications capability. Drones will operate within an 8 km radius[63] of each other in order to maintain LoS communications. This will allow the drone swarm to pass data to each other in a network until the information can be received by a monitoring ship/aircraft/shore establishment. Thus, any adversary entering the A2/AD region will be detected and targeting information passed to the next layer of the A2/AD zone. It is also key to note that this initial layer will operate both within and without the specified A2/AD region. This will allow target approach to be detected sufficiently far away to provide the next layer of UUVs with ample time to intercept.

The second layer of the proposed denial zone will consist of UUV weapon delivery systems.[64] These drone *motherships* will transit into the A2/AD region[65] before setting down on the sea bed[66] to conserve power and minimise detection by the adversary's maritime-, space- or air-based assets. Each delivery platform will passively monitor for an acoustic signal from an allied warship/submarine or air-dropped sonobuoy that will activate them. Upon activation, each drone will ascend and connect into the communications network of the detection layer UUVs and assimilate target

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[63] LoS range (nautical miles) =2.25 x (√height of antenna 1 + √ height of antenna 2) = 4.5 NM for a 1m antenna = 8.33 km. Equation taken from https://www.egmdss.com/gmdss-courses/mod/resource/view.php?id=2220

[64] Button et al., 'A Survey of Missions . . .; 30.

[65] XLUUVs have expected ranges of 2,000 nautical miles. Richard Scott, 'USN Fleshes out Plans for XLUUV Programme', *Jane's International Defence Review* 52, no. 4 (29 March 2019): 1–2.

[66] Or at a neutrally buoyant depth.

track data.[67] Once target orientation has been achieved, each delivery platform will proceed at stealth maintaining speed towards the projected target track. Multiple drones will coordinate their movement using the first layer communications network to ensure that dynamic changes to target track can be effectively countered. Once within passive sonar range of the target flotilla, all active communication will cease and the delivery platforms will descend to weapon release depth to preserve stealth and avoid adversary detection. To minimise adversary target reaction time, weapons release will be delayed until very high probability of target intercept is achieved, ideally occurring after the adversary was inside the nominal maximum surface ship torpedo detection range of 1,500 m.[68] This weapon deployment concept adds risk that the UUV will be able to be successfully targeted by the adversary but this is offset by the key strength of unmanned systems i.e. the lack of the requirement to preserve human life within the submersible. Defending against weapons delivered in such a manner will be very difficult for the target to achieve and will rely on acquiring effective countermeasures that may not yet exist to defeat the attack.

POTENTIAL COUNTERMEASURES

Traditional anti-torpedo countermeasures have focussed on the target vessel manoeuvring to avoid the incoming weapon whilst activating acoustic decoys and jammers.[69] Manoeuvrability would still be the key to defeating weapons aimed at mobility kills owing to the much higher accuracy required to hit a smaller target with a lower yield warhead. However, the stealth element of the weapon's approach would provide little warning to the target vessel, thus rendering little time to manoeuvre.

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[67] Lockheed Martin, 'Orca - Extra Large Unmanned Undersea Vehicle (XLUUV)', 2020, https://www.lockheedmartin.com/en-us/products/orca-extra-large-unmanned-underwater-vehicle-xluuv.html.

[68] Hyunjin Cho et al., 'A Study of the Effectiveness Analysis for Survivability of a Surface Warship from a Torpedo Attack', *Journal of Simulation* 13, no. 4 (2 October 2019); 311.

[69] *Ibid*.,

Employment of Close-In Weapons Systems (CIWS) would potentially be able to target and destroy a pop-up attack from an EMP torpedo, however the low height of detonation, coupled with the short time airborne, would make this a low probability defence.[70]

Active acoustic hunting of drones is another method that could be used to counter drone attack. An idealised solution would be to utilise a hunter-killer drone screen deployed by adversary vessels to sweep ahead of the task group. However, this would be a relatively slow endeavour as the screen would have to operate at a speed significantly faster than the task group, severely limiting the endurance of the drone.[71] As such the task force would be either constantly recovering drones to refuel and therefore limiting the speed of advance of the adversary fleet or they would be expending drones at a very high rate and therefore be limited by their supply. Furthermore, high-speed drones preceding the adversary fleet would be acoustically loud and sensed well ahead of the fleet's arrival, providing better targeting information and time for the defender's A2/AD construct to react to. Use of adversary Extra-Large UUVs (XLUUVs) with lightweight anti-drone weapons would be an option, however these drones operate at very low speed and as such would have to be deployed significantly in advance of the main task force, thus limiting tactical manoeuvring options.[72]

[70] For example, the Raytheon Mk 15 Phalanx 1b CIWS has a minimum elevation of -25^{o,} an elevation train speed of 92^{o}/s and a traverse speed of 126^{o}/s. The EMP weapon would be undetected by the CIWS until it had attained sufficient height out of the water that the search radar could illuminate it (dependent on ship height and distance from the ship) thus leaving the remaining fractions of a second for the weapon to traverse and elevate and the fire control radar to lock on before firing. This could be successful if the CIWS is set to automatic and the torpedo makes the pop-up attack within a 60^{0} arc of the CIWS initial aim point. Jane's Group, 'Weapons:Naval - Mk 15 Close-in Weapon System (Phalanx)', *Jane's Weapons:Naval*, 2020, 1–18.

[71] Button et al., 'A Survey of Missions . . .; 84. Conservative assumption made that the UUV is as efficient as a current Heavyweight Torpedo with a max range of 12.5 nm. Jane's Group, 'Spearfish Mod 0'.

[72] Janes, 'Echo Voyager', *Jane's Unmanned MAritime Vehicles*, 2019, 1–3.

A further possibility would be to make use of existing Anti-Submarine Warfare (ASW) assets within the adversary fleet. Manned submarines and ASW helicopters are both optimised for hunting submersibles attacking the main fleet.[73] However, detection probability will be extremely low. Drone delivery vehicles are much smaller and acoustically quieter than even the stealthiest manned submarine[74] and they can shut down fully to become completely silent. Furthermore, use of active sonar by hunting submarines exposes the hunters to counter action by the hunted; this is not a tactic that is commonly used by attack submarines as it renders them easily detectable and thus vulnerable.[75]

Aside from detection and destruction of the attacking drones, defensive measures could be taken to reduce the effect of the impact of the mission kill weapons on surface combatants. Shielding propeller shafts with armoured plating would potentially prevent small warheads from achieving individual effect however, for known shielded targets, multiple weapons would be used against the same target or a heavier explosive yield incorporated into a drone warhead.

The most effective defensive measure to be taken against a drone A2/AD screen would be to employ cyber weapons to degrade or disable the system operation as the adversary task force approaches. As the concept of operations requires significant, if low rate, wireless communication in order to function, there will always be a potential avenue for cyber exploitation. This would exploit the cyber defence vulnerabilities

[73] Joetey Attariwala, 'The Art of Helicopter Anti-Submarine Warfare', *Naval Forces* IV (2017): 32–35.

[74] Bryan Clark, 'The New Enemy Below', Centre for Strategic and Budgetary Assessments, 2017, https://csbaonline.org/about/news/the-new-enemy-below.

[75] Steven Stashwick, 'US Designing New Unmanned Vehicles to Help Its Subs Detect Adversaries', *The Diplomat*, 2017; 1–3; David Owen, 'Stealth and Silence and Underwater Hunting 1960–1992', in *Anti-Submarine Warfare : An Illustrated History*, First (Barnsley: Pen & Sword Books, 2007); 615.

inherent in collaborative unmanned systems where ‘it is not feasible to build defences against all such [cyber] threats’ against autonomous vehicles.[76]

LEGAL CONSIDERATIONS

Ensuring compliance with the International Humanitarian Law (IHL)[77] is a significant consideration that must be taken into account by Western militaries when designing a maritime unmanned A2/AD zone. The key concern in this scenario is complying with the IHL principle of distinction[78] i.e. how accurately could the unmanned system differentiate between adversary vessels and other, uninvolved or civilian, traffic? To date, there is no agreed upon answer to this problem other than to have a human make the decision to employ the weapon systems.[79] This could be done relatively simply by inserting a human intervention step between the acquisition of the adversary fleet by the outer detection layer and the authorisation of the weapons platforms to engage. Satisfaction of the principle of distinction would, by default, satisfy the remaining IHL targeting criteria in relation to civilians.[80] Nevertheless, there will still remain the question about the ability of drones to recognise when combatant vessels have been rendered *hors de combat* versus those remaining viable (and therefore legal and ethical) targets.[81] As such, for lethal weapon employment, there will be a continuing requirement for human intervention capacity once drone weapons have been employed.

[76] Bharat B. Madan, Manoj Banik, and Doina Bein, ‘Securing Unmanned Autonomous Systems from Cyber Threats’, *Journal of Defense Modeling and Simulation* 16, no. 2 (2019); 132.

[77] As specified in the Geneva Conventions of 1949.

[78] International Committee of the Red Cross, ‘Protocol Additional to the Geneva Conventions of 12 August 1949, and Relating to the Protection of Victims of International Armed Conflicts’ (1977); Article 48.

[79] Peter Asaro, ‘On Banning Autonomous Weapon Systems: Human Rights, Automation, and the Dehumanization of Lethal Decision-Making’, *International Review of the Red Cross* 94, no. 886 (2013); 708.

[80] If the weapons can be accurately targeted against military targets only then there is no further risk of civilian casualties. Hence the principles of proportionality and precautions in attack are satisfied.

[81] Paul Scharre, *Army Of None: Autonomous Weapons and the Future of War*, First (New York: W. W. Norton & Company, 2018). 258-261.

However, the requirement for distinction and the potential for strikes on vessels *hors de combat* would not be as critical when employing non-lethal weapons as IHL is primarily concerned about preventing civilian and non-combatant casualties. If the weapon has an extremely low probability of causing such casualties[82] then there would be no requirement to have a human in the loop. Subsequently, the A2/AD zone could be run in autonomous mode, thus freeing up scarce (and highly expensive) manned naval assets for other tasks. The worst-case scenario is that a merchant vessel is incorrectly targeted and struck by non-lethal weapons, completely disabling it and requiring rescue. This would cause significant political embarrassment to the A2/AD employing state and require financial reparations to be made but, there would be no breach of IHL and the subsequent international condemnation that would bring. Politically, this 'lesser evil' may be more palatable than conceding territorial advantage to an adversary, especially if the purpose of the A2/AD zone is to protect allies or weaker states from unwanted aggression.

CONCLUSION

Creating a credible maritime A2/AD zone that does not require extensive, and therefore expensive, manpower to maintain will be a goal of states (such as the US) which desire to operate such zones far from their own borders. The advances made in all fields of unmanned vehicles in recent decades has enabled multiple technologies to be developed for use in the underwater battlespace. In particular, the breakthroughs in control technologies, coupled with increased power density of battery systems, have set the scene for disruptive uses of UUV technologies in the future. Long-range, high-endurance sensor vehicles networked into a swarm configuration will become the

[82] It is impossible to rule out all eventualities and therefore civilian casualties cannot be ruled out completely.

backbone of a sensor system for A2/AD application. Linking into this sensor net will be the autonomous weapon delivery platforms, able to stealthily approach an adversary fleet intent on encroaching into the denial zone. However, the weapons delivered from the drones do not need to be of the lethal variety. The capability to target specific structures of a warship with non-lethal force to obtain a mission kill will provide both strategic and tactical options to a state engaged in competition below the threshold of war. Legally, the involvement of a human-in-the-loop, able to make the firing decision (and therefore be accountable for the end result) will be required for lethal force to be countenanced. However, this is not the case when utilising non-lethal munitions as without casualties there is no breach of IHL and fully autonomous systems will be legally acceptable. From the adversary's perspective, countering an unmanned A2/AD zone will be difficult to achieve. The technology required to make use of counter drones is not yet advanced enough to match the requirements of an attack fleet advancing into defended territory. Furthermore, whilst conventional methods for hunting submarines can be employed, UUVs are extremely hard to detect by conventional ASW methods. Undetected and undisturbed, the employment of unmanned drones to deliver non-lethal deterrence effect on an adversary's fleet is a viable maritime A2/AD option for the future.

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