SEA POWER CENTRE - AUSTRALIA

AN EFFECTS-BASED ANTI-SUBMARINE WARFARE STRATEGY

Working Paper No. 19

Commander Mark Hammond, RAN

Published by the Sea Power Centre – Australia
Department of Defence
Canberra ACT 2600

ISSN 1834-7231
ISBN 978 0 642 29653 5

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Commander Mark Hammond, RAN, is an Australian submarine commanding officer with sea experience in Royal Australian Navy *Oberon* and *Collins* class submarines, United States Navy *Los Angeles* class, Royal Navy 'S' class, French Navy *Amethyst* class and Dutch Navy *Walrus* class submarines. The author has completed the Royal Netherlands Navy Submarine Command Course, the RAN's Principal Warfare Officer Course and the Australian Command and Staff Course. He is currently the Commanding Officer of the *Collins* class submarine HMAS *Farncomb*.

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Abbreviations and Acronyms

ADF	Australian Defence Force
ADHQ	Australian Defence Headquarters
ASW	Anti-Submarine Warfare
CIWS	Close-in-Weapons System
DE	Decisive Effects
DSTO	Defence Science & Technology Organisation
EBO	Effects-Based Operations
EE	Enabling Effect
EHF	Extra High Frequency
ESM	Electronic Support Measures
ET	Enabling Technology or Tactic
FFG	*Adelaide* class guided missile frigate
FPS	Functional Performance Specification
HQJOC	Headquarters Joint Operations Command
HSV	High Speed Vessel
JTF	Joint Task Force
MEU	Mission Essential Unit
OODA	Observation, Orientation, Decision, Action
RAN	Royal Australian Navy
R&D	Research and Development
SES	Surface Effect Ships
SHF	Super High Frequency
SLOC	Sea Lines of Communication
SM	Submarine
SURTASS	Surface Towed Array Sonar System
SWATH	Small Waterplane Twin Hull
UAV	Uninhabited Aerial Vehicle
UUV	Uninhabited Underwater Vehicle
US	United States
USN	United States Navy
WWII	World War II

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Introduction

The Imperial Navy's neglect of anti-submarine warfare (ASW) ... proved deadly to the wartime Japanese merchant marine, but the Japanese submarine force was also ... poorly prepared to cope with US Navy ASW operations.[1]

— Carl Boyd and Akihiko Yoshida, 1995

... the most complex form of war at sea — ASW — has become even more so. Submarines, purposes, and owners have all proliferated.[2]

— Charles W. Koburger Jr, 1997

The Past

In 1945 Japan lost the ability to exploit the natural resources that she needed to continue the war against the United States (US), predominantly because her merchant shipping transiting her sea lines of communication (SLOCs) had been decimated by American submarines.[3] US submariners had achieved decisive results against Japan, whereas their German U-boat 'peers' ultimately failed against Britain in both World Wars.[4]

Peter Padfield credits the Allied 'technology advantage' as being decisive, particularly praising centimetric radar, ULTRA code breaking and communications, while Peter Kemp also credits the Convoy System.[5] What is seldom effectively highlighted, though, is the fact that US submariners seized and maintained their advantage against Japan by applying new technologies and tactics at a rate that continually mitigated their own weaknesses, targeted the enemy's and capitalised on their own strengths.[6] Paradoxically, the German U-boats were outpaced by similar British anti-submarine warfare (ASW) efforts from mid-1943.[7]

However, none of these tactics or technologies proved decisive in themselves. Rather, they each contributed to form a system of capabilities that collectively conspired to defeat the enemy. The combination of air power, radar, ULTRA and convoy, together with proficient weapons and tactics for engaging the submarine, collectively won consistent victories in encounters that the Allies were previously resigned to losing. Furthermore, the British and the Americans employed new tactics and technologies at a pace that exceeded the enemy's ability to counter them. It might therefore be argued that the victors operated inside the enemy's technical and tactical decision-making processes or 'reaction loops', rendering a 'compound advantage effect'[8] to those with the initiative, and 'compound disadvantage' to the reacting side. In any event, Japan failed to appreciate the threat posed by the US submarine campaign, and the Germans failed to counter the voracity and growing potential of the British ASW campaign. But that was when submarines presented a tangible and credible threat.

The Present

In 2003 there were 53 new diesel-electric submarines at sea worldwide, each less than five years old. Of these, countries geographically located between Australia, Pakistan and China owned 45 (or about 88 per cent).[9] There are now more than 78 diesel-electric submarines aged less than ten years, and almost 170 in total (more than half of the global diesel-electric submarines stock) operating in this region.[10] It is difficult to find a similarly 'over-represented' military capability so close to Australia and our SLOCs.

Officer of the Watch on periscope on HMAS Collins

Furthermore, many older submarines are now being replaced or upgraded with advanced sensors and weapons to enable them to stand and fight in shallow littoral waters, permitting 'routine missions in waters too shallow to enable the submarine to go deep and hide'.[11] Advances in propulsion systems, hull design, sensors and weapons are being regularly introduced into new submarines. Unprecedented levels of stealth, combat data processing, firepower and endurance now reside in the cheapest of modern diesel-electric submarines.

Today, a single diesel-electric submarine can fire and control up to four torpedos simultaneously, and each torpedo is capable of sinking a large merchant vessel or a medium-sized warship. A typical World War II (WWII) style submarine patrol, conducted by a modern 21st century diesel-electric submarine, could therefore result in as many as 20 such vessels sunk, a result achieved only by the most successful wolf packs in all theatres in WWII. Couple this with the fact that modern tankers are up to ten times bigger than the largest vessels afloat in WWII, and the damage done by a single diesel-electric submarine could exceed one million tonnes in a single patrol, or maybe in a single salvo.

The Future

This Working Paper proposes an ASW strategy that blends the advantages of lessons learnt from both the 'historical' and 'material' schools of maritime strategic thought with modern philosophies of effects-based operations and the observation, orientation, decision and action (OODA) Loop.[12] It begins by making some key definitions before articulating a generic, albeit unclassified, profile of the submariner decision-making process during a torpedo attack – 'the Submarine Attack Cycle'. This process is then analysed to determine critical points at which it 'must' be broken, yielding an ASW strategy model with inherent decisive 'effects' that, when achieved, conspire to defeat the submarine OODA Loop and attack cycle. A brief examination of the technology environment is conducted to examine how capability development decisions can be consciously prioritised to ensure that ASW decisive effects are targeted efficiently and effectively. Finally, this Working Paper proposes an indicative anti-submarine strategy model for adoption by the Royal Australian Navy (RAN).

Effects-Based Operations (EBO) Theory

Effects-based philosophy describes physical, functional or psychological outcomes, events or consequences that result from specific actions.[13] The Australian Defence Force (ADF) currently operates within a national effects-based construct. As shown in Figure 1, the philosophy views military units (Means) as providing a variety of military options (Ways) for achieving strategic objectives (Ends).[14] In this manner technological changes to naval forces (Means) impact the 'effects' that they can generate and, consequently, the Ways in which Ends can be achieved.[15] It is therefore appropriate to use EBO philosophy to interpret the impact of technology upon ASW capability.

The EBO concept seeks to draw together all elements that can contribute to achieving a specific outcome and views these components in concert, as a 'system of systems' rather than systems in isolation. The resultant 'compound' effect is therefore dependent on the efficiency and effectiveness of all of the individual systems and the manner in which they are coordinated. At the strategic level the EBO model analyses the options for achieving a desired 'end state' by combining the efforts of both military and non-military resources in order to achieve specific effects. At the operational and tactical levels a 'system of systems' approach uses predominantly, but not exclusively, military components to achieve desired outcomes or effects.

An effect is defined as the physical, functional or psychological outcome, event or consequence that results from specific military or non-military actions at the tactical, operational or strategic level. A 'decisive effect' is an effect that will either achieve an end state or complete a phase in a military operation. An 'enabling effect' is an effect that adds to the system of effects designed to produce a decisive effect.

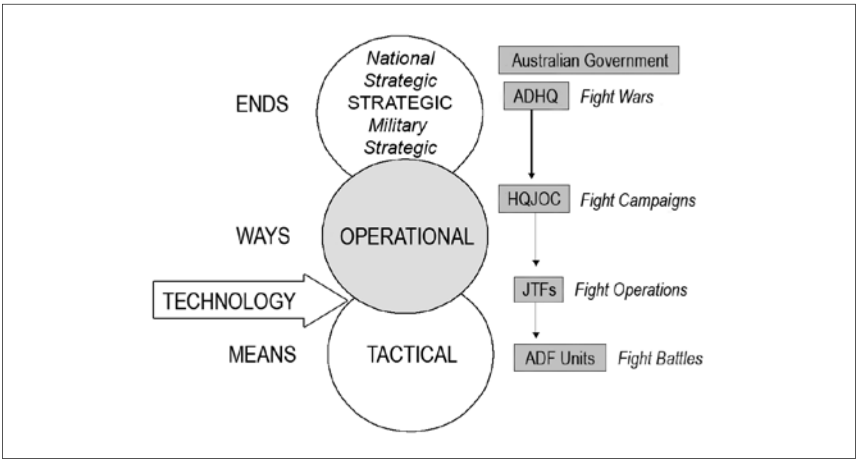


Figure 1: ADF Command, Effects Based Operations & Technology

This Working Paper examines the decisive effects central to ASW and argues that by completely achieving any one of these, or by significantly achieving all of them simultaneously, it is possible to negate the threat posed by a hostile submarine. These decisive effects can be identified by systematically analysing the submariner decision-making process through the framework of the OODA Loop.

The OODA Loop

Colonel John Boyd, United States Air Force (Rtd), developed the concept of the 'OODA Loop' (Observation, Orientation, Decision, and Action) during the Korean War and it is now common terminology in military and business environments alike.[16] His model articulates the human decision-making process in terms of these four simple steps: 'observation' of the environment; 'orientation' within the environment to determine action options; the 'decision' to take an action; and, the 'action' itself. Each step takes time and is interconnected by feedback loops and hypothesis tests. The more complex the environment, the longer it will take to reach a correct decision. The level of environmental complexity therefore contributes to the 'cycle time'.

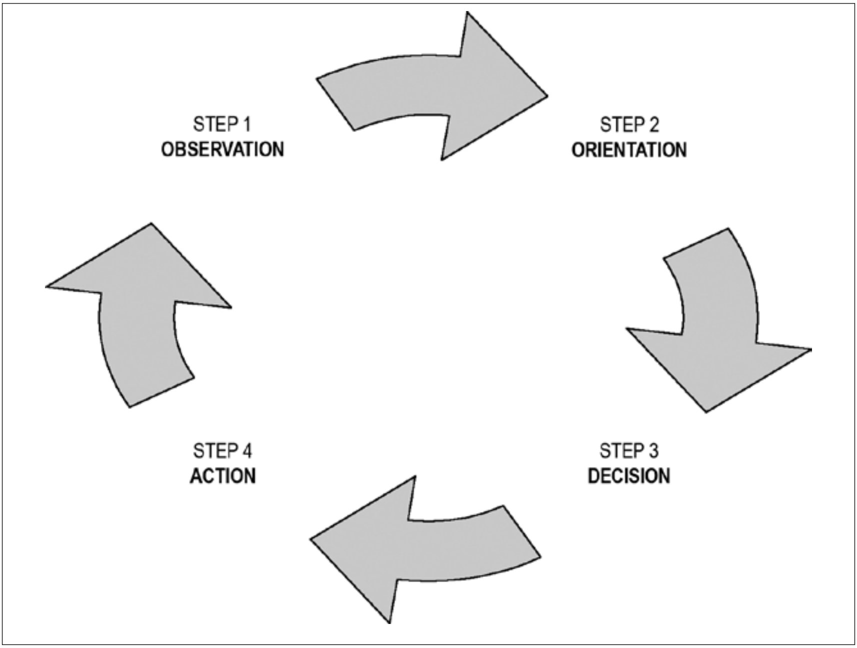


Figure 2: Simplified OODA Loop

Edward Smith describes the effect of ‘disrupting’ the enemy’s OODA Loop and extending his cycle time, citing an event involving Japan’s Vice Admiral Nagumo during the Battle of Midway in June 1942.[17] An intelligence coup ceded the initiative to the American forces (effectively simplifying their operating environment) while the surprise arrival of US forces prompted Nagumo to make a series of decisions that disrupted his planned attack against Midway. This ultimately left Nagumo’s forces exposed to a poorly planned but fortuitous torpedo bomber attack that sank four Japanese aircraft carriers. The Japanese command organisation was effectively halted at the Orientation step while the Americans pressed home their attack.

The upshot of Smith’s analysis of Midway is that the event was decisive, if not pre-planned, and that deliberate emulation of the circumstances that afforded the tactical initiative is extremely desirable. An understanding of the enemy’s OODA Loop and cycle time is therefore a significant advantage in any military engagement.

The OODA Loop theory can also be used to explain the submarine attack process in general, non-technical terms because, like Vice Admiral Nagumo, the submarine captain and his crew employ sensors to gather information that informs their decision-making process as they work toward an accurate fire control solution.[18] Furthermore, the submariner’s operating environment is often complex and difficult to interpret, giving rise to potentially extended cycle times and creating opportunities to ‘get inside the adversary’s decision cycle’.

Submarine Operations

The Submarine Attack Cycle aligns closely to the OODA Loop concept. During operations a submariner continually employs sensors or takes action to maximise opportunities to gain or exploit tactical information, while seeking to minimise the risk of counter-detection. Inevitably though, the submariner transitions through the attack phase shown in Figure 3 before firing a weapon at a target.

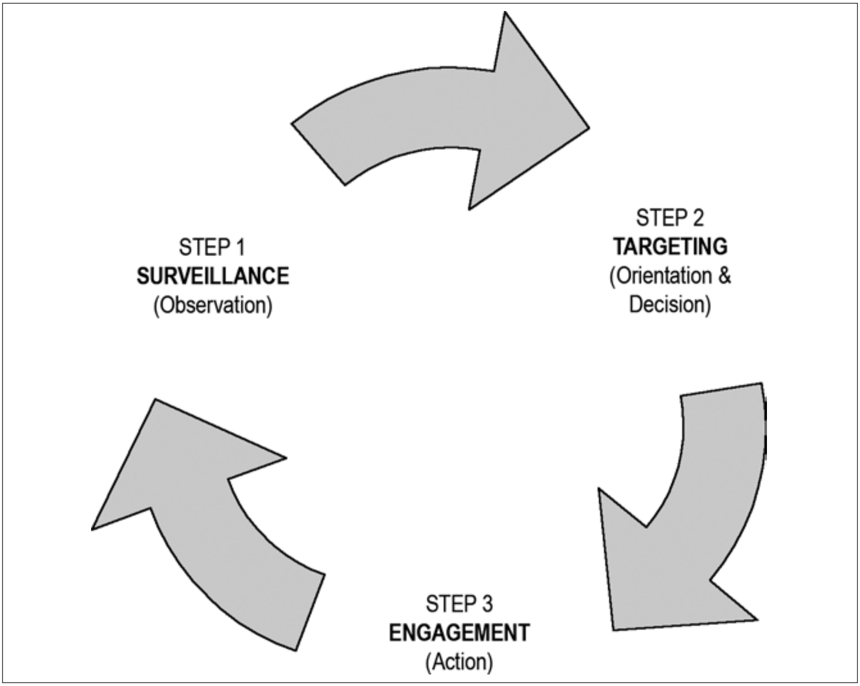


Figure 3: The Submarine Attack Cycle or OODA Loop

In Step 1, the Surveillance phase, the submariner studies its environment for information betraying the presence of enemy vessels. This phase corresponds with the ‘observation’ step. The submariner aims to detect all vessels and aircraft by using various, predominantly passive, sensors (e.g. sonar, electronic support measures, etc), initially sorting them by bearing and intensity.

Step 2, the Targeting phase, aligns well with the 'orientation' step, albeit with some overlap with the 'decision' step. Targeting is sometimes broken down further into localisation and classification steps. Localisation involves sensor and submarine employment to gain and exploit tactical information for determination of contact bearing, range, course and speed (to provide intercept and fire control solutions). The classification step aims at identification of class, origin and threat level of each contact detected (to confirm the contact as a valid target or as a priority target). Ultimately, both processes amount to orientation within a complex environment.

Finally, the submariner moves to the Engagement phase, deciding to conduct an attack and carrying out the attack itself. The Engagement phase may consist of interception and/or missile or torpedo attack, but it will invariably seek to target those units believed to be essential to the enemy mission. The 'action' step clearly aligns to this phase.

All phases may occur rapidly, but quality results are most likely to be achieved if the process is conducted sequentially. The whole cycle may take several days for a submarine receiving third party cueing, or less than an hour if relying on organic sensors. They must, however, all occur before the submarine weapon enters the water and it is this certainty that provides the focal point for a successful anti-submarine warfare strategy.

Furthermore, each phase can itself be termed 'decisive' if it enables the achievement of a specific goal. That is, if the submariner's mission is to detect and track a specific target (e.g. so that it can report the vessel's location, movement or operating profile) then Step 2 is itself decisive. It is therefore appropriate to state that the submarine OODA Loop has three fundamental decisive effects – Surveillance, Targeting and Engagement.

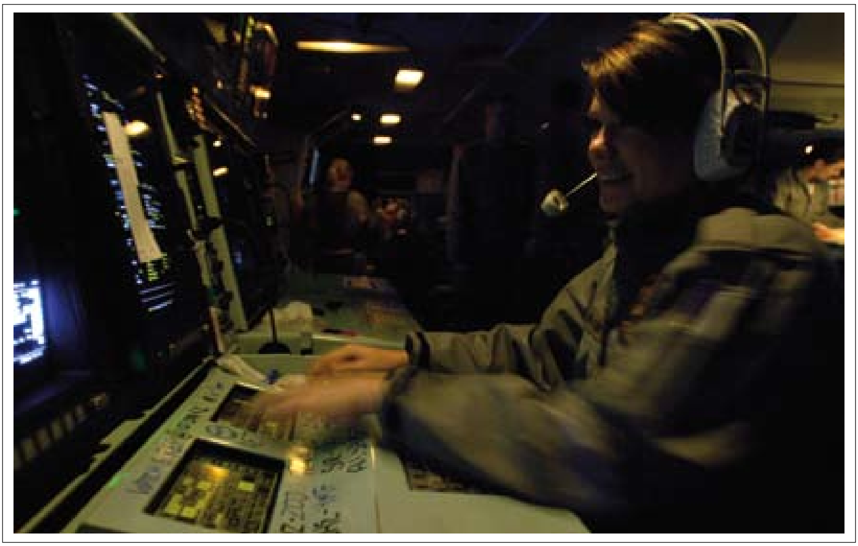
The modern submariner employs a mature, flexible and practical process for stalking and attacking its targets, a process refined over more than one hundred years in some navies.[19] One might then expect a similar maturity in ASW strategy. However, whereas submarines have consistently enjoyed realistic employment and strong political support in many navies throughout the Interwar years, the same cannot necessarily be said for ASW forces. Perhaps it is time to start again.

An Anti-Submarine Warfare Strategy

The ultimate goal of ASW is to destroy or neutralise enemy submarines. The traditional focus of ADF anti-submarine tactical and technological development has resulted in platform-centric acquisition of several capabilities that operate either separately or collaboratively in support of this mission.[20] The traditional RAN 'layered' approach has seen the acquisition of both medium- and short-range sonar equipment, a foray into long-range surface vessel towed array sonar, lightweight torpedos and the IKARA torpedo system.[21] However, while the maritime patrol aircraft capability has been maintained and upgraded, helicopters fitted with dipping sonar have come and gone.[22] Furthermore, depth charges, torpedo nets, anti-submarine mines, harbour defence booms and ASW mortars — once the bane of a WWII submariner's life — are no longer in RAN service.

This situation was perhaps inevitable in peacetime navies forced to respond to budgetary pressures in a climate where force protection in peacekeeping operations has been a paramount concern. Irrespective of the causes, ASW capability has undeniably suffered in both the RAN and the United States Navy (USN), as recently highlighted by the USN Chief of Naval Operations. In fact, the USN recently established a separate Task Force ASW, a team of dedicated ASW officers and scientists with a remit to improve the ASW capability of the USN.[23]

The challenge then is to determine how to best achieve this imperative in the current fiscal climate. In other words, where should we focus our efforts now in order to maximise the cost-benefit equation for new capabilities? With so many technological options and so much pressure to ensure available funds are spent wisely, we must carefully decide what to purchase today, and where to apply research and development (R&D) efforts for tomorrow. It is this dilemma that might be countered most efficiently and effectively by employing an Effects-Based ASW Strategy Model.



Seaman Combat Systems Operator on a console in the Operations Room on HMAS Ballarat

Developing the Effects-Based ASW Strategy Model

Having defined key terminology, it is now possible to analyse the Submarine OODA Loop through the effects-based framework in order to develop an ASW strategy. Analysis of the different phases inherent in a typical submarine attack cycle has already identified an underlying sequence of key objectives that the submarine must achieve before conducting a successful attack: Surveillance, Targeting and Engagement. It follows that any contending strategy might possess as its core goals the exact opposite, as a starting point at least. This gives rise to the ASW Cycle and what will be termed the fundamental Decisive Effects (DE) of ASW: No. 1 Counter-Surveillance, No. 2 Counter-Targeting and No. 3 Counter-Engagement.

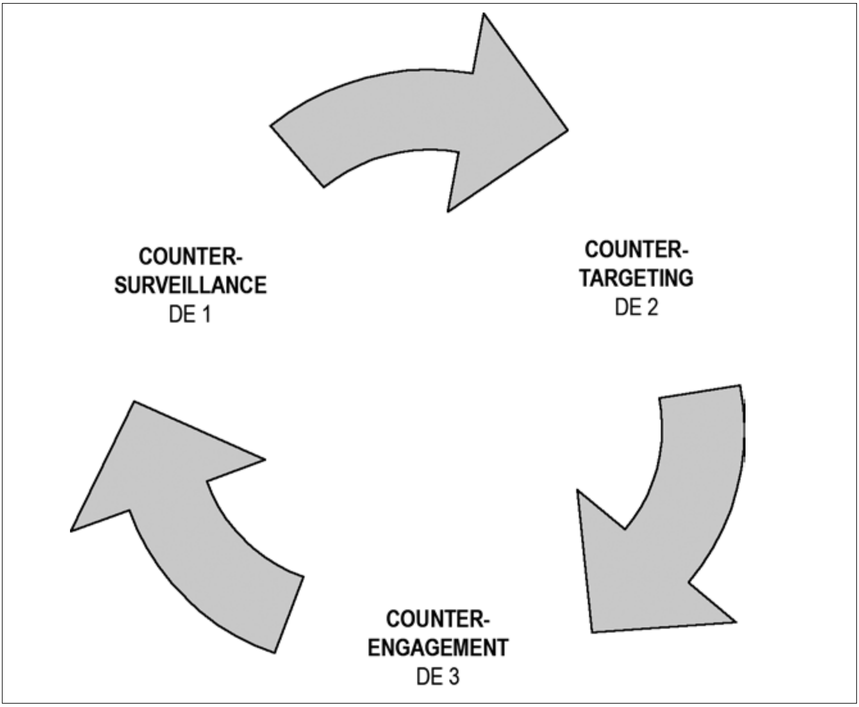


Figure 4: The ASW Cycle

If these effects are decisively achieved then the Submarine Attack Cycle will be broken and the submariner will be unable to achieve its surveillance, targeting and/or engagement mission. If each effect is only partially achieved then the submariner OODA Loop cycle time is extended, affording more time for additional ASW efforts in support of the compound advantage effect. Pursuit of these goals directly targets the submarine's capability and inevitably complicates its operating environment, elevating its risk of defeat.

It is therefore this cycle that should determine how and where we apply tactics, technology and psychology as enabling effects to achieve the decisive effects that consistently defeat the submariner's overall strategy and tactics. Intuitively, this approach will then provide a tool for identifying capability areas that can be improved in order to maximise the strategy's effectiveness. In order to build this model effectively though, we need to develop a deeper understanding of the process of submarine attack in order to develop a strategy that counters all of its varied aspects. That is, we need to identify the elements that enable the submariner to achieve its decisive effects. In EBO terminology — we need to understand the submarine's enabling effects and how it achieves these so that we can identify the enabling effects inherent in the ASW model.

The threat posed by a submarine lies in its ability to continuously complete its attack cycle with impunity. That is, to detect, target and engage surface vessels, submarines and land targets while remaining undetected. It achieves this primarily by stealth, essentially blending into the environment while homing in on its target using predominantly passive sensors, including third party targeting.

This capability can be enhanced in littoral waters where reverberation from active sonar and higher background noise levels significantly mask the presence of a technically/tactically proficient submarine. However, the littoral environment is also one of the most complex that a submariner can confront, often containing high densities of fishing and merchant traffic, and this leads to an extended 'cycle time' for even the most competent crews. In this manner the submariner is constantly engaged in a battle for information while minimising risks of collision, grounding and counter-detection.

Each phase in the attack cycle is therefore enabled by surveillance efforts requiring sensor employment in a complex environment. Sensors used to interpret this tactical information can be broadly categorised as either 'passive' or 'pro-active', where a pro-active sensor is any sensor whose employment creates an opportunity for the submarine to be counter-detected (e.g. raising a mast or antenna).[24] Each sensor is an 'enabling technology' as it enables the submarine to achieve enabling effects within the attack cycle, and each 'sensor employment tactic' is an 'enabling tactic'.

Figure 5 shows a 'skin deep' breakdown of some sensors used by the submarine to achieve Decisive Effect No. 1 (the Surveillance phase) and the types of questions that can reveal ASW enabling effects, technologies and tactics that might support the Counter-Surveillance decisive effect.

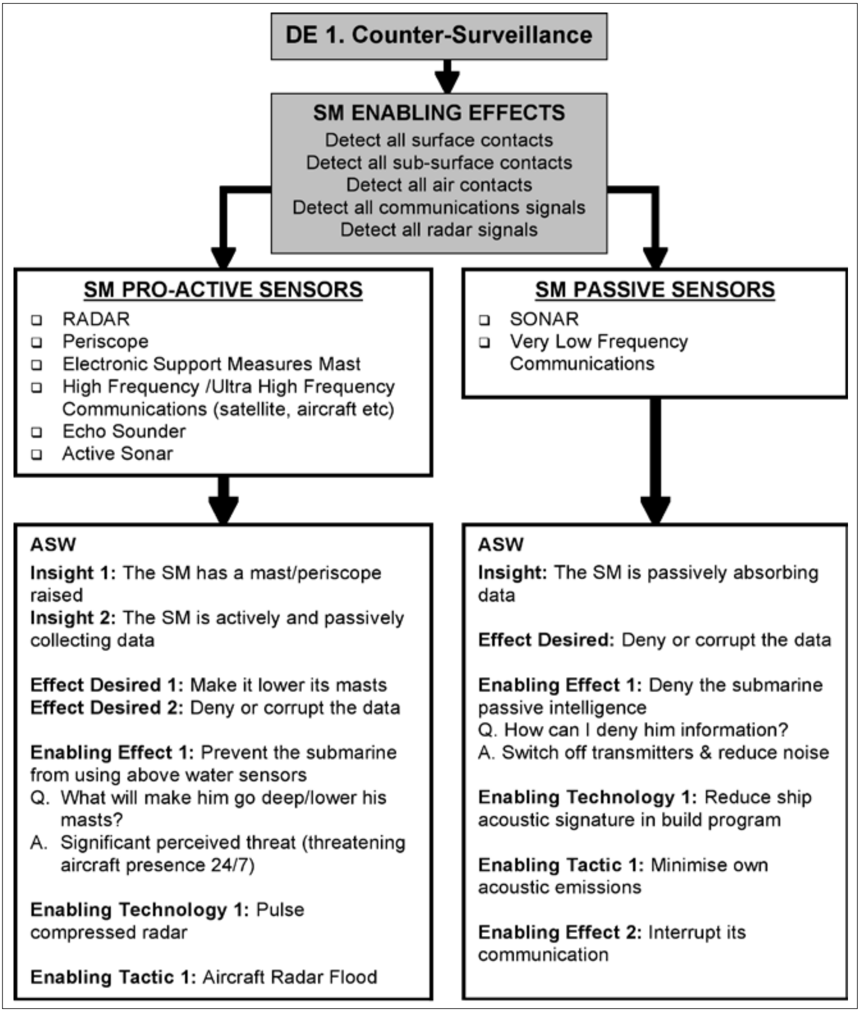


Figure 5: Indicative Development of Counter-Surveillance Enabling Effects and Technologies

In Figure 5 the submarine pursues its decisive effect of surveillance by employing enabling technologies — the pro-active and passive sensors — to achieve enabling effects that collectively reveal the presence of all contacts in the operating environment. This profile should therefore be analysed to determine how these efforts could be interrupted or defeated in order to deny data from the submarine. This objective (denial of data) is termed an enabling effect as it directly supports the decisive effect of counter-surveillance. We then identify tactics and technologies that readily support these enabling effects.

The EBO approach therefore encourages us to view situations from a holistic perspective. For example, it assesses each compulsory act or process that the submarine must perform to achieve its mission and identifies those as desirable targets that should be prosecuted by ASW actions or capabilities. It makes us look at the various sensors that require the submarine to be at periscope depth (e.g. to raise an antenna or mast) and encourages us to interpret this as a counter-detection opportunity. We then ask the question 'How do I prevent the submarine from operating at periscope depth?' because denial of this capability will impact the submarine's attack cycle. 'Denying the submarine an ability to operate at periscope depth' becomes an enabling effect as it contributes to the decisive effects — counter-surveillance, counter-targeting and counter-engagement.

Of note, concurrent with this physical cycle, the submarine's captain is likely to be engaged in a constant mental and psychological process that creates an opportunity for the surface forces. The instant many submariners become aware that they are increasingly likely to be counter-detected their over-riding priority changes from 'mission completion' — that is, sink the Mission Essential Unit (MEU) — to evading contact and ensuring their submarine survives the encounter. To do otherwise — that is, to ignore the developing threat to the submarine — can result in a higher probability of both mission failure and own submarine destruction. An EBO approach includes a consideration of this human element, recognises the psychological opportunity, but nonetheless maximises the prospect for detecting and engaging the submariner who pursues his attack regardless of the perceived risk.

Next, analysis of each sensor and its method of employment allow us to determine whether they support enabling effects within the surveillance, targeting and/or engagement phases. The EBO model gradually identifies the relationship (relationship mapping) between each submarine capability and the decisive effects they support within the Submarine Strategy Model as depicted at Figure 6.

The model also articulates how each enabling technology or tactic (ETs) can contribute to one or more effects. For example, the green ETs contribute to three or more enabling effects, the yellow ones two or more, and the blue ones to two or more decisive effects

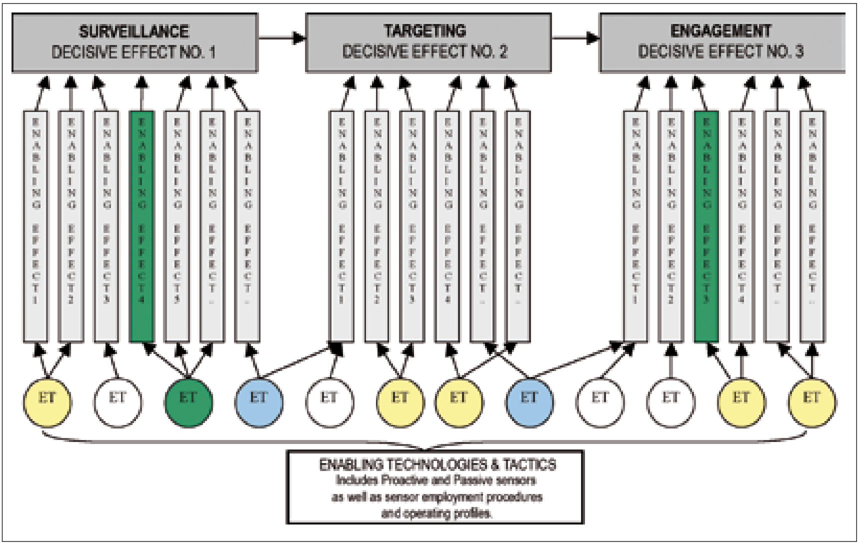


Figure 6: The Submarine Strategy Model

via enabling effects. Similarly, the green enabling effects (EEs) impact the decisive effects more significantly than the others. In this manner we can identify the high pay off enabling effects, technology and tactics to better inform cost-benefit decisions concerning capability development while simultaneously targeting our capabilities directly at our core objectives.

These submarine enabling effects and capabilities can then be targeted by ASW technology and doctrine to determine ASW capabilities that are, in essence, the enablers that underpin an effective anti-submarine strategy. By tailoring our enabling effects and technologies to defeat the submarine's enabling effects, technologies and tactics, we will systematically engage its core capabilities in a holistic manner. Figure 7 indicates how this would begin to grow for the submarine's surveillance decisive effect.

This process creates a model that targets the submarine's decisive effects, enabling effects and enabling technology and tactics simultaneously. Submarine capabilities (technology and tactics) that cannot be readily countered by ASW capabilities will therefore be readily identified and can be singled out for R&D effort. Submarine capabilities that are effectively countered by more than one ASW capability may reveal redundancies or areas of excess effort, allowing resource efficiency improvements. The end result is a juxtaposition of the

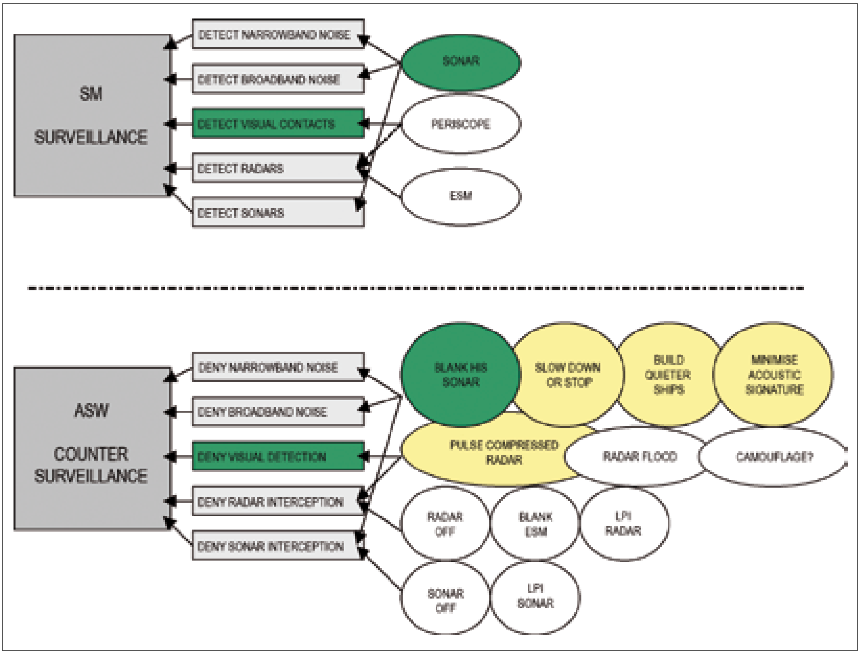


Figure 7: Building the ASW Strategy Model

submarine and ASW models that, when fully developed and with all of the classified fields populated, would readily indicate the balance of power between an ASW force and its submarine threat, and a road to redressing shortcomings. Fittingly, the complete ASW strategy model (as shown at Figure 8) would look similar, albeit opposite in focus, to the submarine strategy model.

The model at Figure 8 is indicative, as much of the data required to accurately build the model is classified and therefore beyond the scope of this Working Paper. That said, a forum of ASW professionals, submariners and scientists could soon populate the various levels with existing technologies to better understand how various ASW capabilities interact and, more importantly, where the existing gaps lie. This model does, however, provide a framework for articulating the technological and tactical linkages, relationships and opportunities inherent in the complex ASW problem, an understanding of which is currently lacking.

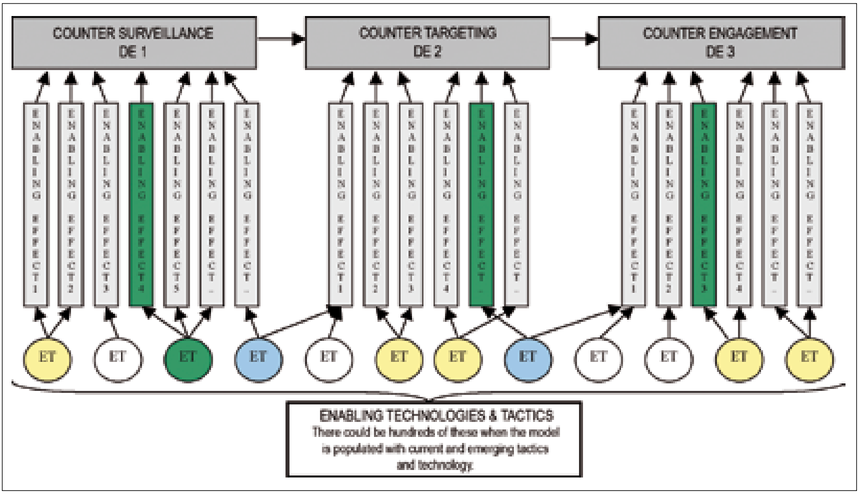


Figure 8: The ASW Strategy Model

In summary, the Effects-Based ASW Strategy Model articulates an ASW cycle with inherent enabling effects that can be pursued separately or concurrently in order to decisively break the submarine attack cycle. Each partial success directly impacts the submariner OODA Loop, extending decision cycle times and creating a compound advantage for the ASW force. The next section will examine the emerging technology environment to highlight some opportunities and trends for future ASW.

Applying Technology to Achieve Effects

Having developed the ASW Model it is now possible to see where and how current technologies best contribute to solving the ASW problem. It is also now possible to examine the emerging technology environment to identify future enablers that can enhance our ASW capability.[25]

Emergent technologies are '... technologies that may impact on future naval ship design and construction'.[26] Typically, this genre is constrained to relatively mature, prototype proven or funded technologies. While other 'conceptual' technologies exist, it is difficult and perhaps premature to attempt qualitative description of their potential impact until they have made the difficult transition from theory to prototype.[27] For the purpose of this Working Paper, emergent technologies will be reviewed in four fields: hull forms, propulsion systems, sensors and weapons.

Hull Forms

Modern warships are typically mono-hull vessels designed to maximise capabilities such as payload, seakeeping ability, power projection and survivability. Forecast developments in hull design include advanced mono-hull and multi-hull designs, such as planing hulls, hydrofoils, wave piercing and deep vee hulls, catamaran and trimaran, wave piercing, small waterplane twin hull (SWATH) and surface effect ships (SES).[28] To gauge their impact on ASW, these developments should be interpreted in the context of the effect created by the technology upon the platform.

All of these developments increase vessel speed and efficiency (hydrofoils > 60 knots, deep vee > 55kts, wave piercing mono-hulls: sea transport > 30 knots).[29] As such, it is possible to predict a trend toward faster, more efficient naval vessels that have greater endurance. It is also noteworthy that many designs inherently reduce vessel draught and acoustic signature.[30] These attributes were examined in the context of high speed vessels (HSVs) in the RAN 2003 *Headmark* Experiment. The experiment demonstrated that HSVs provide excellent manoeuvre warfare capability in shallow littoral environments while producing significant targeting problems for surface and (most importantly) sub-surface opponents.[31] However, as discovered by the US, effectiveness is attenuated by poor seakeeping in seas greater than eight feet.[32] This deficiency might be overcome by advanced trimaran designs.

Trimaran designs afford hull drag reductions of 20 per cent or more while simultaneously enhancing the seakeeping qualities expected of conventional mono-hull designs.[33] Similarly, surface effect designs permit a catamaran hull to 'ride' over a cushion of air maintained between the hulls, reducing drag and noise signature and permitting beaching in some conditions (subject to the propulsion system).[34] Clearly, the trend is toward faster, quieter and more efficient shallow draught vessels.

There will also be continued advances in submarine hull design. While propeller and propulsion changes account for the majority of speed improvements in current diesel-electric and nuclear submarines, advanced streamlining is becoming increasingly important. Vortex control devices and eddy break-up devices were used to counter hydrodynamic flow issues (with associated noise and speed consequences) on both the RAN *Collins* class and USN *Seawolf* class submarines.[35] This has had the effect of reducing acoustic signature and fuel consumption while increasing speed and endurance.

In summary, potential improvements in hull design produce the physical effects of improved fuel efficiency/endurance, reduced acoustic signatures, increased vessel speeds and improved access to shallow water. This bodes well for principles of tempo-based strategies like manoeuvre warfare, especially in the littoral. These trends may be further enhanced by propulsion system developments.

Propulsion Systems

Propulsion systems include propellers, propulsors and associated fuel and auxiliary systems. Forecast developments include enhanced electric propulsion, fuel cell technology, water-jet propulsors and super-cavitating propellers. Again, these developments seek to increase vessel speed, efficiency/endurance and/or to reduce acoustic signatures. It is important to note, however, that propulsion efficiencies can also enable greater power generation to support weapons and sensors.

Conventional marine propulsion systems convert mechanical, gas or steam energy into rotational propeller or directional water jet motion, while separate power generation sources provide for sensor, weapons and ancillary demands. Enhanced electric propulsion systems, as envisaged by the US Electric Ship concept, centre on integrated power systems that use electric motors driven by a common power generation system to simultaneously provide power for sensors, weapons and auxiliary demands.[36] This reduces the size and complexity of the power generation/propulsion system, freeing up space for other capabilities while improving fuel economy by 15-19 per cent. Translated to the maritime environment, this has produced more effective conventional submarines with greater endurance and increased stealth. Just as the automotive industry is investing increasing amounts of money in electric propulsion and hybrid car designs, it can be expected that hybrid ship designs will also follow. Perhaps the Royal Navy's Type 23 frigates and Type 45 destroyers represent a portal to the future of quiet, fuel efficient ship design.[37]

Fuel Cell technology and Air Independent Propulsion are also likely to become more common.[38] German Type 212 submarines are at sea today, propelled by fuel cells. The technology has also been tested in a USN surface vessel. Fuel cells create electrical energy from chemical reactions without moving parts, generating less heat and acoustic noise than conventional combustion processes.[39] However, there are associated speed limitations, usually below four knots.[40] Overall, the technology affords increased stealth, endurance and efficiency.

Water-jets provide increased efficiency for vessels in the range 25-40 knots. Located near the surface, they also allow a shallower vessel draught. Super-cavitating propellers also improve vessel efficiency by increasing thrust, allowing speeds measured in hundreds of miles an hour.[41] The cavitation effect does increase noise signature, however, super-cavitation technology may yet revolutionise naval power in the same way that the supersonic jet impacted air power.[42]

To summarise, advances in propulsion technology are likely to increase naval vessel stealth, speed and efficiency, with some technologies again enhancing shallow water efficiency and access. These improvements appear to reinforce hull design advances, potentially auguring an era of faster, shallower draught, quieter and more efficient naval vessels. Again, manoeuvre warfare concepts are reinforced. However, future naval forces will require an array of intelligent sensors to maintain situational awareness to exploit enhanced battle-space access and manoeuvre.

Sensors

The Defence Science & Technology Organisation (DSTO) notes that 'Sensor development appears to be growing at an exponential rate in miniaturisation, sensitivity and applications'.[43] Furthermore, predicting future sensor capabilities out to 30 years is significantly problematic because '... unpredicted technological advances can render systems obsolete mid development'.[44] However it may be possible to draw some relatively robust conclusions by reviewing current developmental efforts.

Some remote-controlled and autonomous sensors are already mature, particularly uninhabited aerial vehicles (UAVs) and uninhabited underwater vehicles (UUVs). The *Anzac* class frigate HMAS *Warramunga* has controlled, tasked and received sensor information from a UAV.[45] The US has completed more than three hundred UUV missions including mine-warfare operations in Umm Qasr during Operation IRAQI FREEDOM.[46] Future developments may include submarine launched UUVs capable of conducting reconnaissance, mine-laying, inshore photography and beach survey work.[47] UAVs similarly permit operations behind enemy lines or in contested air space where the risk of casualties is unacceptable. Further advances in robotics and miniaturisation of power sources will increase the endurance, dexterity, reliability and flexibility of these platforms, perhaps rendering current maritime patrol aircraft redundant.

Communication data-rates have steadily increased in the past 30 years and this trend is likely to continue. Directional extra high frequency (EHF) and super high frequency (SHF) communications now enable platforms to transmit high volumes of information (including video) instantaneously, rendering forward deployed units (e.g. submarines and Special Forces) almost undetectable by today's interception technology. Furthermore, there have been advances in covert underwater communications that enable submarines to communicate with other submarines, ships, bottom sensors or sonobuoys without being detected.[48] This technology may eventually control UUVs, or switch on or off remotely activated mines. The effect created by this technology is one of enabling and exploiting covert, integrated operations in hostile environments — again, enhanced battle-space access.

Sonar technology is also proceeding apace. Multi-beam technology has enabled three-dimensional seabed mapping for commercial purposes. An early version called 'Petrel' is now being fitted to RAN frigates as part of the FFG Upgrade Program. The equipment enables real-time seabed analysis for mine avoidance, navigation and submarine detection. Similarly, submarines will be able to exploit this technology to aid navigation in shallow water, opening safe access to previously unsurveyed (or poorly surveyed) archipelagic waters, and enabling inshore mine-laying operations without the need to return to periscope depth to receive satellite navigation data. Other submarine detection advances include explosive echo ranging, low probability of intercept sonar and low frequency active passive sonar (to detect submerged submarines at greater distances).

Radar surveillance is becoming increasingly supported by satellite technology. Medium navies, embracing the network enabled concept, are also realising the theatre level surveillance opportunities afforded by satellites using a range of detection, classification, and intelligence collection and communications capabilities. However, other technological advances are decreasing submarine and ship vulnerabilities by improving stealth, counter-detection, early-warning and decoy systems.

It is therefore difficult to quantify the gains that might be realised as improvements in related fields vie for ascendancy in detection capability on the one hand, and stealth on the other. However, the future ASW battlespace might yield networked forces informed by a diverse array of advanced organic and remote sensors,[49] enabling greater access to the maritime battlespace and greater certainty in the maritime picture than is currently available. ASW forces will consequently demand longer range, more responsive and increasingly accurate weapons systems to establish a reach advantage over their adversaries.

Action in the Control Room as HMAS Dechaineux *surfaces*

Weapons

Weapon systems can be broadly categorised as either above-water or below-water. Above-water weapons are employed against surface vessels, aircraft and, increasingly, land targets. Below-water weapons target a vessel on or below the sea surface — primarily submarines and ships. The objective is usually to destroy or damage the target; though in effects-based philosophy the right terminology might be to 'neutralise the effectiveness of' the target. Future weapon systems will also exploit emergent technologies, and increasingly target them too. Both above-water and below-water categories will be scanned noting that the submarine employs weapons in both environments.

Naval gunnery now employs rocket-propelled munitions, improved computer-aided targeting and rapid-fire technology such as Metal Storm (one million rounds per minute, infinitely variable rate of fire).[50] Rail guns and pulsed power systems are now being developed for electric ships that will still be in service in 30 years time.[51] Missile technology, whether ship, submarine or air launched, arguably demonstrates the same trends. Terminal homing capabilities now exploit third-party guidance (e.g. laser designation) as well as providing options to home on heat or infra-red signatures.

Similarly, laser technology continues to produce potential weapon applications, including missile defence. Solid-state laser technology will permit efficiencies that allow employment on naval vessels. High power microwave weapons are also on the horizon (2010), and variants called Masers (Microwave Amplification by Stimulated Emitted Radiation) may permit the employment of multi-megawatt pulses of radio energy against the electronics in missiles, UAVs or aircraft.[52] The 'effects' of these developments against air, land or sea targets include extended range, improved rate of fire and, in some instances, improved accuracy and effect.

Advances in below-water weaponry, like sonar technology, continue relatively unabated. The future generation of torpedoes and mines may be able to: recognise and counter most decoy systems; recognise and target specific vessels; exploit bottom topography to aid stealth while homing; and engage at extended ranges that negate improvements in counter-detection technology, while remaining undetected until a point at which the kill probability approaches certainty. However, other advances may provide new challenges. Super-cavitating bullets could produce an underwater close-in weapon system (CIWS) capable of engaging torpedos during their terminal-homing phase.[53] In fact, Dunk suggests that submarine technology advances will outpace anti-submarine developments, citing a reduction in effectiveness of maritime patrol aircraft as one likely result.[54]

Again, the pace, complexity and diversity of developments render it difficult to predict a resultant 'balance of power' between stealth and detection. Perhaps it is more productive to simply surmise that weapon engagement ranges and accuracy are likely to improve. However, a significant shift in the balance could result from a revolutionary development, such as the ability to 'see' underwater to a range of 30 nautical miles or more, or the ability to consistently destroy torpedos or mines prior to impact/detonation. Similarly, electromagnetic interference technologies may find significant utility against a network-enabled opponent.

Hypotheses aside, the net effect of naval weapon development seems to point toward increasingly accurate, longer range, more reliable systems with greater rates of fire and lethality. The arrival of laser and microwave weapons, as well as highly advanced underwater systems, may shift the focus from attrition of equipment to neutralisation of systems through targeted electromagnetic interference. Ultimately though, the continuing battle between development of detection and targeting systems versus counter-detection and counter-targeting systems render it difficult to predict revolutionary impacts in this field.

HMAS Rankin *returns home to Fleet Base West after a six-month deployment overseas*

Implications for ASW

The examination of technological developments reveals several trends. Firstly, hull design improvements offer improved fuel efficiency/endurance, reduced acoustic signatures, increased vessel speeds and improved access to shallow water. Propulsion system advances also suggest that an era of faster, shallower draught, quieter and more efficient naval vessels has arrived. Sensor developments are numerous but decisive trends are difficult to quantify. However, there are indications that access to the maritime littoral battlespace will be improved, supported by greater certainty in the maritime tactical picture than is currently available. Finally, weapons system developments indicate some uncertainty concerning the balance of power between submarine strike capabilities and ASW, amid an overall trend toward increasingly accurate, longer range, more reliable systems with greater rates of fire and lethality.

These observed trends might seem innocuous at first. However, the level of certainty appears to be higher in the hull and propulsion fields than in the sensor and weapon fields. Couple this with the long lifetime expectancy of maritime platforms (e.g. in excess of 20 years for most aircraft and ships) and it can be surmised that investment in hull and propulsion enabling technologies will likely produce desired results with long-term application. Contrast this with a new weapon development that takes several years to design and certify for use, which is then fitted to a ship at the mid point of its life cycle, and then gradually becomes less reliable and perhaps ultimately unsustainable over time. Worse still, these developments can become obsolete within a short time due to the rapid development of warfare technologies.

Furthermore, as the model shows, the submarine must conduct surveillance and targeting as a precursor to engagement so it is constantly reliant on an acoustic, radar or visual detection of the ship. Any technology or tactic that reduces acoustic, radar or visual signature therefore offers both immediate and long lasting rewards. Given that hull and propulsion improvements impact all three submarine decisive points, all of the time, in any environment, then the advantages of spending money to reduce the acoustic signature (and therefore vulnerability) of a ship in the design and build phase are significant.

The model can also be applied on a unit by unit basis. By doing so we see, for example, that HMAS *Sirius* would blend into the electronic support measures (ESM) background by equipping it with the SPS55 radar fitted to the escorts. Or better yet, we could provide all surface vessels with pulse compressed navigation radars, thereby adding immediate anti-submarine capability without necessarily closing up the radar operator. The mere presence of a pulse compressed radar (which, unlike conventional radars, provides no tangible ‘threat threshold’ to the submarine ESM system) directly affects its ability to operate at periscope depth.

Several cost/benefit decisions readily become apparent too. Ideally, we could develop a surface naval force with common, limited probability of intercept pulse compressed radars so the submariner would be confronted by a multitude of identical ESM intercepts, which only betray the presence of a large force that may, or may not, include a MEU. This would also result in a reduction in the number of different radars at sea, realising cost savings in both upkeep and training, while enhancing ASW capability. If this force could only be detected acoustically at short range, for example 20,000 yards, then electromagnetic emission control silence would mean fewer submarine interactions, and fewer losses in war. In some cases, a submarine achieving detection may yet lack sufficient warning to achieve tactical advantage through positioning without increasing its own signature by accelerating – more money saved without necessarily investing heavily in more expensive, often developmental weaponry.

It can therefore be argued that the Effects-Based ASW Model meets the as yet elusive requirement for informing cost effective, capability multiplying application of technology by articulating the problem in a coherent yet comprehensive format.

In effects-based ASW, detection and destruction of a threat submarine are viewed as components, not the 'must-do' objectives, of a holistic anti-submarine warfare strategy. The EBO approach takes a wide view of the submarine's capabilities and weaknesses, considering all components of the ASW problem – ranging from the functional performance specifications (FPS) for defence capital acquisition programs to perception management in the threat submarine's Command Team – as opportunities to be exploited. Detecting the submarine is still viewed as important as an enabling effect, but is only rated as a decisive effect if, in itself, it achieves our mission and 'negates the submarine threat'.

This approach to ASW has yielded a cascading model with several strengths, whether viewed from capability development or warfighting perspectives. The model articulates the links between capital acquisition decisions and the impact on the ability to achieve decisive warfare effects. It also articulates the compound effect of disparate capabilities (tactics and equipment) working in concert to achieve decisive warfighting outcomes (or 'effects'), while identifying the capabilities that contribute to more than one outcome and therefore warrant higher priority. The model simultaneously highlights outcomes that are desirable but not supported by a current capability or tactic (capability gaps) and shows how the 'decisive effect potential' of our net ASW capability can be damaged by removing a capability or by failing to provide a capability to support an enabling effect.

Detection and destruction of the submarine through sensor and weapon employment is only part of the ASW problem and, according to the trends in emerging technologies, these are also the most difficult fields in which to gain or hold a decisive advantage. However, we could only avoid a fight for a limited time. Sooner or later warships may be forced to stand and fight against submarines and they will need the best available tools to detect and sink their targets. To that end we are compelled to continually improve our anti-submarine sensors and weapons because decisive counter-engagement is likely to remain the only 'checkmate' move in ASW.

Conclusion

> *Whatever we decide, I trust we will not be left with hollow forces. It will cost us most if we become only a paper tiger. In case anyone forgets, sea lines of communication ... is really what ... navies [are] in the end all about.*[55]
>
> Charles W. Koburger Jr, 1997

This Working Paper introduced an EBO approach to a core maritime warfare problem in order to identify the underlying issues that must be addressed by an effective anti-submarine warfare strategy. Although we are intuitively doing many of the things highlighted by the model, it can be seen that unless we coordinate our efforts effectively while simultaneously exploring all of our options, we will not achieve our full potential. Developing a solution lies in examining the problem in a coherent manner that informs the decision-making processes that impact on our capability to fight and win at sea. The ASW Strategy Model provides this service.

It is arguable that a modern diesel-electric submarine, competently handled, could close a significant choke point (e.g. the Malacca Straits or Bass Strait) for an extended period while causing a huge amount of damage and loss of life. Such a scenario would also likely result in a significant environmental problem, especially if a 500,000 tonne tanker was destroyed. Similarly, given the nature of our modern globalised world trade system, many stakeholders would be significantly affected by the closure of a strategic trade route. For a nation like Australia, with little significant nationally flagged shipping, such an incident would be potentially crippling as our 'suppliers' would head for safer waters. The stakes are indeed high.

An EBO approach to warfare is a multi-dimensional problem solving approach that recognises the importance of achieving a desired effect as a driver for decision-making. The systems approach inherent in EBO can enable us to exploit the full range of technical, tactical and psychological enabling effects to defeat the submarine mission. By adopting this approach to the ASW problem we can create a robust, coherent model that enables us to identify the capabilities we need to do a job and how they should interact in a complimentary manner. Development of this model will form the basis of an effective ASW strategy that is both holistic and objective, and provides insights relevant to many defence organisations. There may even be potential for it to be modified for other maritime warfare disciplines.

Unfortunately this model only provides a mechanism for identifying what we should do to maximise our ‘decisive effect potential’. Naturally, we cannot have it all. However, by using this model we can identify our deficiencies and determine where we should apply the resources we do have. It helps us to understand our vulnerabilities so that we can apply effort to strengthen them while simultaneously exploiting the submarine’s weaknesses and countering its strengths. It may be that the right balance is both affordable and achievable and can provide the capability to achieve enough compound advantage to effectively counter a low to middle capability diesel submarine.

There is not a single ‘magic bullet’ that will win the ASW battle. This, however, has always been the dilemma. In the future ASW battle though, the submarine should be forced to either take increased risks that will enhance our prospects for defeating it, or to accept a reduced impact on the playing field, thereby enhancing our prospects of mission success. The RAN must adopt a cost effective approach to capability development. As demonstrated in this Working Paper, effects-based ASW has the potential to achieve both of these objectives.

Endnotes

1. C. Boyd and A. Yoshida, *The Japanese Submarine Force and World War II*, Naval Institute Press, Annapolis, 1995, p. xii.

2. C.W. Koburger Jr, *Sea Power in the Twenty-First Century*, Praeger Publishers, Westport, 1997, p. 150.

3. S.T. Smith, *Wolf Pack. The American Submarine Strategy That Helped Defeat Japan*, John Wiley & Sons, New Jersey, 2001, p. 293. US 'submariners had, indeed, cleared the seas of enemy ships'.

4. M.C. Meigs, *Slide Rules and Submarines: American Scientists and Sub-surface Warfare in World War II*, University Press of the Pacific, Hawaii, 2002, p. 209. 'The history of the defeat of the U-boat and the parallel successes of the American submarine arm possess an ironic twist.'

5. P. Padfield, *War Beneath the Sea – Submarine Conflict 1939-1945*, Random House, London, 1995, p. 477; and P. Kemp, *Convoy Protection – The Defence of Seaborne Trade*, Arms and Armour Press, London, 1993.

6. US submarines were provided with new torpedos, FM sonar for detecting and avoiding Japanese minefields, forward operating bases to increase patrol efficiencies, and were supported by MAGIC intercepts (Japanese equivalent of ULTRA) and operational and scientific analysis. Meigs, *Slide Rules and Submarines*.

7. Meigs, *Slide Rules and Submarines*, p. xv. Foreword by Vice Admiral J.A. Baldwin, USN. Meigs heralds the application of technology and science as creating the turning point in the Battle of the Atlantic in mid-1943.

8. Author's terminology. Akin to 'compound interest', a compound advantage effect is realised when successive gains are achieved by making more than one breakthrough or technological improvement before the enemy counters the first one.

9. A.J. Watts (ed), *Jane's Underwater Warfare Systems Sixteenth Edition 2004-2005*, Jane's Information Group Limited, Surrey, 2004, pp. 13-14. Analysis of figures by author.

10. There were a total of 168 diesel-electric submarines operated by regional countries in 2003, from a global force of about 300 diesel-electric submarines. This truly represents both the bulk, and the 'cream', 'of the crop' on Australia's doorstep.

11. Watts (ed), *Jane's Underwater Warfare Systems Sixteenth Edition 2004-2005*, p. 4.

12. Effects-based operations are 'coordinated sets of actions directed at shaping the behaviour of friends, neutrals and foes in peace, crisis and war'. E.R. Smith, *Effects Based Operations: Applying Network Centric Warfare in Peace, Crisis, and War*, CCRP, Department of Defense, Washington, 2003, p. 108.

13. Department of Defence, *Future Warfighting Concept*, ADDP-D.3, Defence Publishing Service, Canberra, 2003, p. 11. EBO goes further, talking about decisive and enabling effects and maintains a predominantly strategic focus. However, it is the battlespace effects generated by military units that conspire to provide the military capabilities that underpin naval operations.

14. Department of Defence, *Joint Planning (Provisional)*, ADDP-5.01, 1st Edition, Defence Publishing Service, Canberra, 2002. Figure 1-1, p. 1-2. Figure 1 is based on this reference, modified to articulate the technology input. [Australian Defence Headquarters (ADHQ), Headquarters Joint Operations Command (HQJOC), Joint Task Force (JTF)].

15. For example, firepower, manoeuvre, stealth.

16. <www.mindsim.com/MindSim/Corporate/OODA.html> viewed 3 February 2005.

17. Smith, *Effects Based Operations*, pp. 120-127.

18. A fire control solution comprises an accurate bearing, range (or geographic position), course and speed of the target to enable programming of the weapon's on-board computer for targeting.

19. The Royal Navy and the US Navy, for example.

20. G. Dunk, '2015: Will the Submarine Continue to be Relevant?' in D. Wilson (ed), *Maritime Warfare in the 21st Century*, Papers in Australian Maritime Affairs No. 8, Sea Power Centre – Australia, Canberra, 2001, p. 244.

21. Mulloka Sonar (HMA Ships *Melbourne* and *Newcastle*), SQS 56 (all remaining *Adelaide* class frigates) and Sperion B (*Anzac* class frigates). SURTASS: Surface Towed Array Sonar System. MK 44 & MK 46 lightweight torpedos. Lightweight torpedo airborne delivery system developed by Australia and the US.

22. AP3-C Orion maritime Patrol Aircraft, supported by S-70-B2 Seahawk helicopters. SK50 Sea King dipping sonars, were removed in the 1980s.

23. O. Kreisher, 'As Underwater Threat Re-emerges, Navy Reviews Emphasis on ASW', *Sea Power Magazine*, Vol. 47, No. 10, October 2004, <www.navyleague.org/sea_power/oct_04_15.php>.

24. As opposed to an active sensor, which is one that transmits noise. This distinction is made in this Working Paper as it serves as a discriminator that highlights pro-active actions or events within the submarine's control that 'actively' create opportunities for counter-detection, regardless of noise generated by the action.

25. This section draws heavily on G.A. Clarke and I.A. Burch, *Emergent Technologies for the Royal Australian Navy's Future Afloat Support Force*, DSTO Aeronautical and Maritime Research Laboratory Report (DSTO-GD-0288), May 2001.

26. Clarke, *Emergent Technologies for the Royal Australian Navy's Future Afloat Support Force*, p. 1.

27. Some Australians will remember the paperless, fully integrated *Collins* class submarine combat system designed in the 1980s to take advantage of 'foreseen' technology that today remains elusive.

28. Such as: planing hulls, hydrofoils, wave piercing and deep vee hulls; catamaran and trimaran, wave piercing, small waterplane twin hull (SWATH) and surface effect ships (SES). Clarke, *Emergent Technologies for the Royal Australian Navy's Future Afloat Support Force*, p. 45.

29. Hydrofoils > 60 knots, Deep Vee > 55kts, Wave Piercing Mono-hulls: sea transport > 30 knots. Clarke, *Emergent Technologies for the Royal Australian Navy's Future Afloat Support Force*, pp. 47-48. Increased speed and efficiency is due to less fuel consumption and less hydrodynamic drag.

30. The notable exception is SWATH vessels.

31. Author's observations during the wargaming experiment.

32. G.M. Stewart, *At Sea Experimentation with Joint Venture: October 2001 through September 2001*, CNA Corporation, 2003, p. 48. The project leased a catamaran hull High Speed Ferry, *Joint Venture*, for assessment on behalf of the US Army, US Marine Corps, US Navy and Naval Special Warfare Command to '... explore the concepts and capabilities associated with commercially available advanced hull and propulsion technologies ...', p. 1.

33. Clarke, *Emergent Technologies for the Royal Australian Navy's Future Afloat Support Force*, p. 46.

34. Clarke, *Emergent Technologies for the Royal Australian Navy's Future Afloat Support Force*, pp. 46-47.

35. Similarly, hull designs and coatings are increasingly targeting fouling from marine growth as well as temperature related corrosion issues, both of which are particularly important in Australia's northern environments.

36. C. Petry, *The Electric Ship and Electric Weapons*, presentation to NDIA 5th Annual System Engineering Conference Tampa, Florida, 22–24 October 2002.

37. Other electric propulsion possibilities include advanced permanent magnets and low temperature superconductors, although the scope of this essay does not permit all developments to be covered in detail.

38. G. Dunk, 'Technological and Operational Trends in Submarine Warfare' in J. McCaffrie and A. Hinge (eds), *Sea Power in the New Century*, Australian Defence Studies Centre, Canberra, 1998, p. 182.

39. Clarke, *Emergent Technologies for the Royal Australian Navy's Future Afloat Support Force*, p. 52.

40. N. Friedman, 'Operational and Technological Developments in Underwater Warfare' in McCaffrie and Hinge (eds), *Sea Power in the New Century*, p. 161.

41. Clarke, *Emergent Technologies for the Royal Australian Navy's Future Afloat Support Force*, p. 53.

42. K. Lavell, 'New Technology Transforming Naval Power', <www.signonsandiego.com/news/op-ed/techwar/20030301-9999_mzle2newtech.html> viewed 7 September 2004.

43. Clarke, *Emergent Technologies for the Royal Australian Navy's Future Afloat Support Force*, p. 61.

44. Royal Australian Navy, *Australia's Navy for the 21st Century*, Defence Publishing Service, Canberra, 2002, p. 16.

45. D. Nandagopal, 'Maintaining the Technology Edge in Maritime Warfare for the 21st Century', presentation to Pacific Technology Forum 2004, Singapore, September 2004.

46. T. Schoor, presentation on 'Unmanned Systems Technology for Mine Warfare – AUVSI Unmanned Systems Program Review 2004', Office of Naval Research – Department of the Navy Science and Technology, 12 February 2004.

47. Friedman, 'Operational and Technological Developments in Underwater Warfare', p. 160.

48. HAIL technology by Nautronix Pty Ltd, Fremantle, WA.

49. Defence Advanced Research Projects Agency, *Strategic Thrusts*, <www.darpa.gov/body/strategic_plan/strategic_text.htm> viewed 8 September 2004.

50. Clarke, *Emergent Technologies for the Royal Australian Navy's Future Afloat Support Force*, p. 31.

51. Petry, *The Electric Ship and Electric Weapons*.

52. Clarke, *Emergent Technologies for the Royal Australian Navy's Future Afloat Support Force*, p. 32.

53. Clarke, *Emergent Technologies for the Royal Australian Navy's Future Afloat Support Force*, p. 34.

54. Dunk, 'Technological and Operational Trends in Submarine Warfare', pp. 185, 188.

55. Koburger Jr, *Sea Power in the Twenty-First Century*, pp. 140, 142.

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Glossary

ASW Attack Cycle: The process, or sequence of events, conducted by ASW units to neutralise the effectiveness of an enemy submarine.

ASW Strategy Model: The theoretical model that portrays how ASW forces can achieve their decisive and enabling effects.

OODA Loop: The human decision-making process in terms of these four simple steps: *observation* of the environment; *orientation* within the environment to determine action options; the *decision* to take an action; and, the *action* itself.

Centimetric Radar: Radar of wavelength measured in centimetres provided improved detection and discrimination capabilities ideal for detecting small objects such as submarines and periscopes while operating at a frequency unexpected and, initially, undetectable by the Germans.

Compound Advantage/Disadvantage: A compound advantage effect is realised when successive gains are achieved by making more than one breakthrough or technological improvement before the enemy counters the first one (by operating inside their OODA Loop). The enemy, naturally, experiences a compounding disadvantage that may or may not be proportional.

Convoy System: Merchant vessels were grouped according to speed and sailed as groups to facilitate concentration of escort vessels for their defence. The system meant that U-boats would have to fight their way past military escorts (ships and aircraft) to attack the merchant ships, a much riskier prospect than just attacking a lone vessel.

Cycle Time: The time taken to complete one OODA Loop cycle. This can be extended by factors such as environmental complexity, poor communications etc, or shortened by employing improved technologies and tactics.

Decisive Effect: An effect that will either achieve an end state or complete a phase in a military operation. In the context of this Working Paper, the effect is one that breaks the Submarine Attack Cycle.

Effects-Based Operations: Effects-based philosophy describes physical, functional or psychological outcomes, events or consequences that result from specific actions.

Electronic Support Measures: Equipment used to detect electronic transmissions from other equipment such as radar or communications equipment.

Enabling Effect: An effect that, when achieved, contributes to a decisive outcome or effect.

Enabling Technologies and Tactics: Equipment and tactics that allow the achievement of enabling effects.

Historical School: Views historical events as a potentially accurate indicator of future events. Proponents included Mahan, Corbett and Richmond.

Material School: Centres on the assumption that the dominant military weapon or hardware (the material strength) at a given time is the dominant or decisive factor in war. Douhet, Trenchard and Mitchell are noted Materialists.

Passive Sensors: Sensors that allow the submarine to absorb information without creating a counter-detection opportunity.

Pro-active Sensors: Pro-active actions or events within the submarine's control that 'actively' create opportunities for counter-detection, regardless of noise generated by the action.

Submarine Attack Cycle: The process, or sequence of events, conducted by a submarine during a torpedo or missile attack or intelligence collection operation.

Submarine OODA Loop: The decision phases that overlay the Submarine Attack Cycle.

Submarine Strategy Model: The theoretical model that portrays how a submarine achieves its decisive and enabling effects.

ULTRA: The code used by German U-boats in WWII. Once broken, the Allies could divert their shipping around known U-boat positions.