The Technical Design Gap in Warship Environment Protection: Why 'Near Enough' is Often Better Than Perfect

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ABSTRACT
Many navies aspire to acquire 'fully environmentally compliant' warships, but such statements indicate minimal understanding of what compliance entails, or realisation of the emasculation of ships' operational effectiveness inherent to such ambition. Additionally, inescapable technical realities void any possibility of achieving this aspiration in all but limited circumstances.

Compared with merchant ships, warships have very long lead times in design and build, and limited weight and space reserves for the incorporation of new design elements or equipment. International Maritime Organization (IMO) rules change regularly and are typically promulgated in advance of the technologies needed to comply with such rules, with the rule change acting as the catalyst for the development and production of requisite technologies. This paradigm works well for the timeframes associated with merchant ship construction but is totally unworkable for warship builds. In this context, even though a new or future rule may be known and well understood, no existing or reliable candidate technologies may be available to fulfil that (future) requirement at the time that a warship design or modification needs to be finalised. Even if such technologies exist, they may be immature and therefore represent risk, or otherwise be developed for and optimised for merchant ship application, and hence not be suitable for warships (eg. shock resistance, [inappropriate] capacity or operating parameters compared with merchant ship applications, signature implications, etc). These uncertainties introduce technical risk and invite unintended consequences.

Attempting to build a 'compliant' warship is a Sisyphean task of questionable purpose; this is better avoided by adopting smarter, focused solutions, based upon alternative compliance means using proven technologies and rational environmental risk evaluation.

BACKGROUND: A CONFUSION OF IDENTITY AND PURPOSE?

Protection of the environment is important, but warships are not built and maintained to demonstrate responsible or exemplary conformance with environmental protection rules – they are, or at least should be, built to fight and win at sea. In fact, the current Australian Chief of Navy, Vice Admiral Mike Noonan, advocated this line of thinking when he declared that the Royal Australian Navy (RAN) needed to 'think like a fighting navy'.

Australian strategic doctrine encompasses 10 fundamental principles of warfare, described as '*time proven and fundamentally important to achieving success*' [1, p. 6-2]. The keystone element of these is delineated as **selection and maintenance of the aim**. The same should apply to warship requirements and acquisition - through their governments, national populations invest very heavily in the development, maintenance and sustainment of naval capabilities, with these capabilities expressed through the ships which make up their navies. Both individually and collectively, navy ships – warships – exist, or at least should exist, to best be able to fight and win at sea – which manifests in the associated contexts of lethality and survivability, as being able to defeat an opponent and return home safely.

It is recognised that warships also typically undertake a host of other functions, particularly in peacetime, such as patrolling and surveillance, 'showing the flag' deployments in support of national diplomatic objectives, humanitarian assistance and disaster relief. Navies also exist to effect a standing deterrent, to make a potential adversary deeply contemplate the risks of taking action against the peer with the potent, well equipped navy. Consequently, even in most situations short of high intensity warfare, the effectiveness of a warship – symbolising national strength and resolve, or influencing strategic dialogue with friends and potential foes alike – is firmly embedded in having capable and credible maritime platforms, optimised for the warfighting role all hope will never eventuate. This has been summarised by others as the ability to 'deter, defeat, deny'; nowhere is this expressed as 'overawe with reduced diesel exhaust emission rates'!

Any national effort to acquire and operate warships must have the cardinal intent of providing an effective maritime warfighting platform. Ergo, everything to do with that acquisition should be focused upon that outcome – as an expression of **selection and maintenance of the aim**. There are many other design imperatives for a warship, but all are, or at least should be, subordinate to the primary aim. This includes matters of environmental compliance, especially when otherwise represented by any attempt at 'black letter' adherence to environment protection rule sets not intended to apply to warships, and the onerous, high risk or inappropriate technical 'solutions' which may be associated with such compliance.

Many navies aspire to acquire 'fully environmentally compliant' warships. Where procurement authorities may be tempted to deviate from or dilute this strict aim of providing an effective maritime warfighting platform, they would be well advised to properly consider the parallel risks to national defence. Rational consideration of functions that contribute to warfighting efficiency must not be displaced by false equivalence (ie. a 'fully compliant' warship is not equivalent to an efficient warfighting platform).

Even if such ambition had sufficient merit to pursue and a 'fully compliant warship' could be designed, which is a highly questionable proposition, to maintain such 'full compliance' over the time of build of a typical warship would be exceptionally difficult and expensive - even more so over the time of build of a class of sisterships [2]. Part of the challenge of maintaining warship compliance is due to the inevitable gaps which arise between the rules sets and the technologies intended to ensure compliance, with technical solutions focused upon merchant ship applications and merchant ship design and build chronologies. Given the unique mission requirements and characteristics of the warship design and build process, it is clear that 'perfect' technology for environment protection purposes should often be eschewed in favour of technology which is 'near to good enough'. This could also be labelled as the merit of the pragmatist over the purist.

This paper concentrates upon 'warships' as surface combatants, particularly destroyers and frigates, with the concepts and analyses presented being equally, if not acutely more applicable, to submarines. There is a lesser nexus with larger naval ships and auxiliaries such as afloat support ships, but the general concepts do still hold to varying degrees.

THE WARSHIP ENVIRONMENT PROTECTION TRADE SPACE: 'SLIM PICKINGS'

Like anything, warship designs exhibit finite boundaries – size limitations, space and weight restrictions, limited top weight margins, and cost ceilings – such that compromises need to be made in design selections and equipment fits and the resultant capability expectations. More so than most other ships, and particularly in the case of surface combatants and submarines, whatever is included in a warship design and fit means that something else needs to be left out – the unavoidable 'trade space' conundrum. Merchant ships can 'trade' space for revenue earning capacity per unit or offset increased operating costs by amending their cost recovery structures, neutralised by the fact that their competitors also need to do the same in an internationally regulated 'level playing field'. No such moderating factors apply for warships: nor should any be expected from opposition naval forces.

It is imperative, therefore, that navies adopt an agile, nuanced approach, applying lateral thinking to develop innovative, fit-for-purpose solutions focused upon managing <u>actual</u> environmental risks, rather than simply assuming those risks and their prescribed solutions (often not yet available) arising from the civil shipping sphere. This includes effective evaluation and astute adoption or rejection of the merchant ship-derived technologies which may supposedly be required to achieve environmental compliance, or at least be intended to do so.

THE ORIGIN, INTENT AND FOCUS OF SHIP ENVIRONMENT PROTECTION RULES AND THEIR INTRINSIC AND SYSTEMIC INCOMPATIBILITIES WITH WARSHIPS

The International Maritime Organization (IMO), by charter and precedent, focuses upon civil shipping: IMO environment protection rules, and their nationally legislated derivatives, are of, for and about merchant ships, their risks to the environment and their rational merchant-ship centric means of management. There are myriad reasons why many of these rules cannot be applied to warships, nor need to be.

The fact that these rules are made for and about ships in civil roles is the unavoidable root cause of the technical design gaps which arise in any endeavour to design and equip warships to comply with these merchant-ship derived rules for environment protection. Some of the reasons why these technical gaps arise include:

- The differentiation in timespans for the design and build of civil ships as opposed to those for warships, overlaid with the rate of introduction and change of rules.
- The availability and technical maturity of equipment intended to comply with these evolving rules.
- The minimal weight and space margins available in warships, compared with merchant ships, for the accommodation of equipment and fittings solely for the

purposes of environmental protection, including as may be necessary for new or upgraded equipment associated with amended rules.

- Marine pollution control equipment optimised for application to civil shipping, instead of warships.
- The ‘level playing field’ of regulatory requirements applying to civil shipping, in comparison with the competitive, critical requirements for national defence and the contest for maritime combat supremacy underlying warship design.

These civil ship / warship dichotomies also need to be considered within the paradox that warships present different sorts of risks to the environment, often of different scale and character, than do civil ships: these warship risk profiles are sometimes better, sometimes worse, and sometimes non-existent.

Warship v Merchant Ship Design and Build Periods

The IMO deliberates on environment protection issues via the Marine Environment Protection Committee (MEPC), which meets once or twice each calendar year; rules are consequently changed once or twice annually. New and amended rules span the range from the monumental to the mundane; from design rules changing the general arrangements of ships, to trivial intricacies such as record book layouts.

For each new or revised rule, the IMO also schedules a date for its entry into effect, usually around two to five years in the future. In this context, it is pertinent to consider timelines applicable to the design and build of merchant ships, characteristically short compared with warships. The period for merchant ships from design to keel laying to delivery can usually be measured in tens of months and rarely exceeds a few years. The normal window permitted by the IMO for entry into force of new regulations makes reasonable allowance for adoption by merchant ship designers, builders and operators, such that an infant new design / new build merchant ship can invariably be completed before the new rule enters force.

Merchant ship timeframes are incongruent with the gestation periods for warships, particularly combatants, with lead times and build programs often measured in decades. This has ramifications for achieving compliance during design and initial build, and a compounding problem if intended to maintain compliance throughout a build program and over life-of-type. During the warship design and build period many new environmental rules will emerge, with these nominally applicable to individual ships in a class.

Maritime environment protection rules display constant ‘churn’, becoming more expansive and rigorous over time, simultaneous with an increasing rate of promulgation and amendment. In its first 50 meetings, from 1974 to 2003, the MEPC issued 114 Resolutions, at around four per annum. Its next 23 meetings in the following 15 years generated a further 197 Resolutions, averaging around 13 per annum. This record indicates both the perpetual state of flux of the rule set and its accelerating rate of change.

In the context of this ever-changing rules framework, consider that the IMO deems the date of assignment of new or amended rules to any particular ship on the basis of one or more of a number of factors, with these variously deemed, *inter alia*, as:

- date of build / keel laying;
- date of delivery of the ship;
- date of installation of an individual item of equipment; or
- date of delivery for installation of an individual item of equipment; or
- date of defined 'conversion' for a ship in service.

While these milestones are easily recognisable and relatively straightforward for a merchant ship, warship ‘compliance’ within these sorts of parameters defies meaningful definition. For example, should an individual warship, or class, be ‘compliant’ according to regulations extant at the date of:

- Design finalisation? – noting that the design finalisation may be five years or considerably more before even the lead ship is laid down.
- Contract? – noting that the contract may be signed anywhere from five years to 25 years before the final ship is completed.
- Laying down the lead ship or each individual ship? – considering that the lead ship and final ship of the class may be 15 years or more apart.
- Commissioning (ie. ‘delivery’) of the lead ship or each individual ship? – considering that the lead ship may commission 10 or more years after the design was finalised, with final ship of the class 15 years or more years after that.
- Delivery for installation of an item of equipment for the lead ship or each individual ship? - noting that equipment sets for batches of ships are often purchased in blocks many years before being installed into an individual platform.
- Date of refit/upgrade (ie. ‘conversion’) for the first of the class upgraded, or for each individual ship? – even if such potentially irrelevant or inconsequential design or equipment changes can be accommodated.

In the situation of, for example, the Australian *Hunter* Class Frigate acquisition, based upon a design that matured around 2015 for a final ship to be delivered around 2040, it is reasonable to assume that IMO rule changes over this intervening period would number in the range of 250 or more. Not all new or amended rules would have direct relevance but all would need review and analysis. It is difficult to comprehend how a class of warships could maintain alignment with such a dynamic rule set during their build process. Furthermore, it is questionable whether (perceived) benefits would be worth the penalties, for what may be nothing more than incremental or inconsequential environmental gains, while introducing and compounding technical risks, design complexity and inflated costs.

It is axiomatic that even if a lead ship was, hypothetically and very improbably, fully compliant with applicable environment protection rules during build, the likelihood of retaining this status across sisterships is exceptionally unlikely, particularly with the more complex designs and lengthy build programs of surface combatants.

Any intention for strict compliance is further exacerbated throughout life-of-type as observation of IMO design and equipment rules can mandate replacement or enhancement of existing, or installation of entirely new, pollution control systems at different junctures in a ship’s life. In accordance with many IMO rules, such requirements may be simply as a result of ship age, or be triggered as a consequence of other, potentially even unrelated, refit or upgrade work or modifications. For example, under strict observation of IMO rules, the mid-life upgrade of a frigate with new combat systems and improved diesel auxiliaries would precipitate the consequential need to also add complex exhaust treatment systems to comply with new emission rules. Even the hypothetical conversion of a frigate to a training ship, by the simple expedient of, for example, removing the main gun mount and replacing this with a deckhouse for a classroom may be argued as a change of role, and hence as a 'major conversion' for the purposes of some rules, which could result in the consequential need to make other modifications, potentially extensive, simply to comply with new or amended IMO environment protection rules which would not otherwise apply to that ship.

Some amelioration of inevitable obsolescence over ship build programs can be achieved by forecasting more stringent future requirements (albeit with the real prospect of introducing other risks, and assuming suitable technologies are available and proven). Indeed, some warship types (eg. afloat support ships, large amphibious units) have greater elasticity in terms of weight/space, power and ventilation margins for compliance modifications, than do warships of leaner, optimised design (eg. submarines, destroyers, frigates). Ship upgrades and technology insertions also provide some capacity to regain some level of compliance, but the inevitable and unavoidable trajectory will be of divergence between the nominal rules baseline and individual ship compliance as the build of class of sisterships progressed.

Ballast Water Treatment: An Example of a Merchant Ship-Centric Solution to a Common Risk

With good reason, the IMO has promulgated rules intended to minimise the likelihood that ship's ballast water will act as a transfer vector for marine pest species or human pathogens. The rules sets, and the technological solutions they spawned, are founded upon the way in which merchant ships typically take-up and discharge ballast water, which inversely reciprocates what they do with their cargo loads: rapid, block uptake in one port area; carriage to another port area; and rapid discharge in the new port area. Merchant ship ballast water capacities are typically measured in the thousands to tens of thousands of tonnes, with corresponding uptake and discharge rates in the thousands of cubic metres per hour. Obviously, commercial developers and providers of ship ballast water treatment systems have concentrated on the merchant ship customer, developing large capacity systems optimised for large volumes and rapid rates of ballast water movement.

Compare this with a typical surface combatant, which *may* (but not always) need to uptake or discharge a few tens or hundreds of tonnes (at most) of ballast water in any sequence, with the latitude to do this in a less time compressed manner than merchant ships needing to get alongside a commercial berth within a certain timeframe. The over-capacity merchant ship certified ballast water treatment system may be inappropriate for the warship, being oversized, consuming precious weight, space and power, requiring its own training and logistic support tail, and perhaps performing sub-optimally because it is rarely used as the design intended. This is not to suggest that small capacity ballast water treatment systems are not available, but just as there is merit in modern sailors and ships being able to multi-task, this is also a reasonable expectation for warship plant. Instead of adopting the merchant ship technical solution, warships can achieve the same objective outcome – sanitised water for use as ballast – by using freshwater generated by a ship's onboard reverse osmosis (RO) units.

Consider that in a typical merchant ship, ballast water use for very large cargo compensation systems is some orders of magnitude greater than the fresh water demand for their crews of around 20 to 30 personnel. This contrasts with a destroyer or frigate where large crews impose high demands for fresh water, while the ship presents minimal ballast water requirements. The warship ratio of ballast water to freshwater use is almost the inverse of the merchant ship equation, such that warship fresh water requirements and ballast water demand are commensurate in magnitude. It is intriguing to consider how the IMO's rules for ballast water treatment may have been articulated if the example they were considering was analogous to that in warships, where only a fraction of the water capable of already being treated in a ship was needed for ballast purposes. It must be considered that rather than mandating the development and installation of a totally novel treatment process, the IMO may have adopted the pragmatic approach of adapting existing systems and may have ruled that treated ballast water should be siphoned off from IMO-approved fresh water production systems.

The use of water produced by a warship's RO units, perhaps of augmented capacity to cope with periodic extra demand, may not strictly accord with any IMO-prescribed technical solution for ballast water management. It would, however, certainly result in the same objective outcome while lowering technical risks, reducing costs, simplifying designs and avoiding possible derogation of potential warfighting capability. The parallel use of RO units for ballast water production, rather than a single-use dedicated ballast water unit, also has the benefit of simplifying watchkeeping, maintenance, configuration management and logistic support tasks and costs, all while providing greater redundancy for a mission critical system.

This is a signal example of where declining to adopt a merchant ship tailored technical solution avoids collateral ship warfighting penalties, while still effectively and objectively addressing the subject risks to the environment. A 'near enough' albeit not 'perfect' technical solution which is more than fit-for-purpose.

WORKING WITHIN THE RULES: REALISING OUTCOMES AND NOT SIMPLY GETTING 'TICKS IN BOXES'

IMO conventions address ship-sourced pollution in a variety of ways. The IMO provides a relaxation for warships and does not anticipate that these rules can or should be strictly applied to warships. This is expressed in all of the IMO's environment-related conventions via a general exemption, tempered by an expectation of compliance as practicable:

> *The present Convention shall not apply to any warship, naval auxiliary or other ship owned or operated by a State and used, for the time being, only on government non-commercial service. However, each Party shall ensure by the adoption of appropriate measures not impairing the operations or operational capabilities of such ships owned or operated by it, that such ships act in a manner consistent, so far as is reasonable and practicable, with the present Convention*.

IMO conventions generally permit employment of exemptions and waivers when compliance would be ‘unreasonable or impracticable’. The IMO also foresees avenues for ‘equivalent’ means of compliance, which may be thought of achieving the same objective outcome by mechanisms other than those imposed by the applicable regulation.

Two things are obvious from the IMO rules. The first is that the agency accepts that warships cannot and should not always comply strictly with their environmental rules. Secondly, is a dispensation for alternative means of achieving the intended objective, with leeway for either compliance with a rule’s intent, or non-compliance if no practicable alternative exists.

The IMO’s recognition of these realities can be further reinforced when viewed through a lens of objectivity. The fundamental rationale of any environment protection rule is not for ships to follow the nominated rule, *per se*, but for the environment to be protected from the subject risk – to achieve the same objective outcome. Realisation of this self-evident truth lends itself to focus upon achieving goal-based outcomes for warships, via alternative compliance measures if necessary, including the adoption or tailoring of appropriate and fit-for-purpose technologies, rather than simply cramming in those technologies which may be optimised and mandated for merchant ship compliance.

WHY ‘NEAR ENOUGH’ CAN BE AS GOOD, IF NOT BETTER, THAN PERFECT

It is germane to consider some examples to illustrate why the default application of merchant ship solutions to warships can introduce technical risk and/or result in the application of inappropriate and incompatible technologies. The absorption of these resultant risks and costs to warships may be hard to reconcile with the loss of combat effectiveness when considered in isolation, but is particularly difficult to accept when such penalties would be expected to be absorbed when the resultant environmental benefit is minimal, if not absent.

To illustrate and consolidate the hypothesis that ‘near enough’ environment protection technology is better for warships than ill-advisedly shoehorning in any supposedly ‘perfect’ merchant ship solution, there are considered to be six facets of potential incompatibility for candidate technological solutions. In terms of adoption by warships, prescribed or promoted solutions which may be perfectly suited to merchant ships may be categorised in one or more of the following groups, as technologies which are:

- inappropriate;
- inadequate;
- inopportune;
- inconsequential;
- inordinate; and/or
- inane.

These domains of unsuitability can be used to gauge the efficacy of candidate technologies for inclusion in warships. These themes are examined further below.

Inappropriate Technology: Sewage Treatment Plants and Why the 'Right' Stuff Won't Work Properly in the 'Wrong' Ship

IMO rules for the discharge of processed sewage stipulate a defined standard of treated effluent. The technology service providers have responded to this, in the main, by developing and marketing a range of sewage treatment plants (STPs) based upon membrane bioreactor (MBR) technologies. When properly installed and effectively operated, MBR STPs provide a proven and accepted means by which ships may demonstrate enduring compliance with IMO sewage treatment requirements.

As the name indicates, membrane bioreactors incorporate biological treatment processes. This treatment process relies upon a population of microorganisms to essentially 'eat' the raw sewage, generating a more stable and more environmentally benign 'waste' product from their own organic processes. These microbiological communities work best in steady state conditions, including quantity and quality of their 'food' supply – this translates to near constant input of sewage effluent from the ship in which they are installed. Commercial ships are intended to make money, and the only way to do this is to be operated very regularly, if not all the time. As such, these ships, be they offshore support vessels with 20 persons onboard (POB), or cruise liners with 5000 POB and rapid turnarounds in port, generally maintain the same number of people onboard, and hence a constant and steady upkeep of 'food' to the MBRs. This allows the MBRs to operate as intended, with minimal influent load fluctuations.

Warships, however, do not always operate, and a frigate, for example, can go from a situation of having 10 POB to 200 POB relatively instantaneously, as occurs on the morning of sailing. Naval in-service experience indicates that MBRs often have limited ability to accept such shock loadings, with the microbiological community which may well have died back significantly during the ship's period alongside unable to process the new load conditions. For certain, after a few days the system should have attained a new equilibrium at the higher load levels, but the irony of all this is that the STP will not have been operating at the intended performance level at the very time that it was most critical for it to do so – ie. when the frigate was transiting coastal waters immediately after sailing. This situation is exacerbated in larger warships, such as amphibious units, when 1000 or more extra personnel may be added in a period of 24 hours or so.

This is a clear example of an inappropriate technology for warships – something which may meet the performance specifications on paper and which is understood to work well in merchant ships, but which has limitations in a warship application. Arguably, it may be better to specify an STP for a warship that, hypothetically, is only partly as good as a perfectly functioning MBR unit, but that actually works more reliably when it really needs to - something that works near well enough all the time, rather than 'perfectly' only sometimes.

Inadequate Technology: Anti-Fouling Coatings

Anti-fouling coatings (AFCs) exist for a reason – to limit the amount of biofouling accumulated on a ship over the period between scheduled drydockings. An ineffective AFC is *bad* for the environment, as fouling on a ship increases drag with commensurate increase in fuel burn and emissions of greenhouse gases and other pollutants. Biofouling assemblages also present a risk of the transfer of potentially invasive marine species from one coastal area to another. An additional risk for warships is the increased platform self-noise induced by excessive fouling. These risks and costs can be controlled via the application of an effective AFC which is fit-for-purpose.

Most AFCs rely upon biocidal action, generated by toxic chemicals held within the paint structure, which leads to the release of these biocides into the marine environment. In previous times, some AFC biocides were overly toxic, poorly targeted and featured excessive release rates which resulted in collateral damage in the marine environment. International and national controls have now curbed these excesses, such that biocides now used in AFCs and available in developed nations like Australia are tightly regulated.

Some paint manufacturers now produce biocide-free AFCs, with these essentially working on the concept of a very smooth surface upon which biofouling organisms can find minimal purchase. On the right sort of ship with the appropriate operating profile these paints perform quite well. Essential to the correct functioning of these paints is for the ship to operate relatively regularly, at sustained, elevated speeds, to ensure that any fouling which may have attached is sloughed off. Failure to operate the ship in a matter conducive to effective paint functioning permits fouling to establish and adhere with some permanency. Once some fouling attaches and is not dislodged, not only does it become more securely fastened itself, but it acts as a substrate for the attachment of successive, denser, and more diverse fouling – exemplifying the axiom that 'fouling begets fouling'.

Clearly, specifying a non-biocidal fouling release coating for warships, which routinely spend many weeks or months alongside in extended maintenance or reduced activity periods may be considered as somewhat audacious. In such applications, fouling release coatings often perform poorly, because they are being used in a role for which they were not intended. Rather than derive supposed environmental benefit in abstaining from the use of an approved biocide in a regulated setting, the use of a biocide-free coating on a typical warship is more likely to realise a range of environmental disbenefits, relating to otherwise avoidable pollutant emissions, excess consumption of non-renewable resources, and accentuated marine biosecurity risks.

Thus, any navy seeking environmental cachet by specifying a non-biocidal AFC, not suited to their ships and their operating profiles, is actually likely to create more problems for the environment than it supposedly solves, as well as tactical ones for itself. This is an example of a technology which is inadequate for the fouling settlement pressures typically experienced by warships, while being perfectly suited for merchant ships with their more regular service profiles.

Inopportune Technology: 15 ppm Oily Water Treatment Systems

The current regulations controlling oil filtering equipment specify that water with an oil content of less than 15 parts per million (ppm) can be discharged to sea. This rule was first set by the IMO in 1977. Some argue that the standard is outdated and should be tightened, and the market now offers oily water management equipment purportedly capable of discharges of 5 ppm or less.

Although current regulations do indeed permit the installation of 15 ppm systems in ships, with no indication that the MEPC is considering any tightening of the standard, it is entirely open to speculation whether the same will be true in five years from now. The merchant ship designer and buyer could quite comfortably specify 15 ppm equipment when ordering a new build ship tomorrow, knowing that the ship will be delivered and in service in about 12 months from the date of ordering. The same does not hold true for the warship buyer.

In the realm of warship design, build and acquisition, five years from now, or even 10 years from now, is effectively 'tomorrow' – the design features and equipment configurations specified 'today' are pretty much what is going to be delivered and installed in five, 10 or 15 years from now. By extension, the warship buyer cannot specify 15 ppm oil processing equipment for the ship being ordered tomorrow with the same level of relaxation as his or her merchant ship counterpart.

In the context of warship design and acquisition, specifying equipment compliant with an extant although aged standard, when better performing alternatives are available, may be categorised as a reliance upon inopportune and borderline anachronistic technologies. Foregoing the established for the more capable, assuming no unacceptable technical risks, represents a sensible and responsible means by which to 'future proof' a warship against the advent of more stringent environmental compliance standards which may plausibly arise during that ship's lifetime.

Inconsequential Technology: Protected Fuel Tanks

The slab sided and flat bottomed profiles of merchants ships, coupled with single screw, single rudder fits and minimum crewing often meant the loss of fuel oil to the marine environment following collisions and groundings. The environmental consequences of any such fuel loss are further exacerbated by the persistent, polluting heavy fuel oils used by merchant ships. To address this legitimate risk to the environment, the IMO imposed rules on the size and location of fuel tanks in ships, with the assigned technical solutions centred upon minimum tank / hull separation distances or tank sizings intended to attenuate both the likelihood of loss of fuel oil in the first instance, and the volume of any fuel which may be lost as a result of such incident.

Contrast this with warships, which for other, mission-related purposes, have small, dispersed fuel tanks, use light refined fuels, and have hull forms which minimise the likelihood of hull breach in the event of collision and grounding. Combined with enhanced propulsion, steering and crewing arrangements, the result is that warships are less likely to get into this sort of trouble in the first instance, and less likely to lose oil in the event of such casualty. The IMO-prescribed rules are blind to this reality, however, as they are for good reason focused upon merchant ship risks and remedies – not warships.

In a 'space-poor' warship, any loss of space as would arise from tank/hull separations results in some reduction in weapon and/or sensor fit, range/endurance, and/or crew habitability, none of which can be readily compensated; mandated tank configurations may also compromise damaged stability condition. Application of the IMO rule via the oil outflow performance models, founded upon merchant ship risk factors, can derive similar penalties.

Imposition of the IMO rules for protected fuel tanks in merchant ships to surface combatants represents a clear case of the burden of an ill-considered and poorly targeted technological solution alien to warships for an inconsequential environmental risk [2]. This would be bad enough of itself, but the great irony is that the observation of these merchant ship rules, for an inconsequential risk, would actually more likely have the opposite of the intended effect, by introducing a greater risk of fuel loss from the surface combatant. Examination of the historical record indicates that the most frequent cause of the unintended release of fuel from warships is due to refueling and tank transfers [3]. Considering that compliance with the IMO rules would invariably result in fewer and/or smaller tanks, this would necessitate more frequent refuelling and tank transfers — with commensurate increase in the risk of fuel losses.

Thus, application of a rule not intended for and addressing an inconsequential risk for warships, would result in increased risk to the environment, in parallel with compromising a warship's operational effectiveness. This is an irredeemably perverse outcome, and one better avoided by recognising that warship design features are 'near enough' to what is intended as an objective outcome by the IMO, without the nonsensical penalty of imposing upon one's self the theoretically 'perfect' technical solution compliant with the letter of the IMO rule.

Inordinate Technology: NO_x Exhaust Reduction Systems

The IMO requires ships operating in comparatively small and specially declared nitrogen oxides (NO_x) Emission Control Areas (ECAs) to operate their diesels in NO_x Tier III mode. In this mode, ship diesel NO_x emission rates are reduced to about 20% to 25% of what is permissible in Tier II mode, which applies outside of the ECAs.

The most widely adopted Tier III compliance approach is urea-mediated selective catalytic reduction (SCR) systems. These Tier III systems occupy relatively significant volume, are expensive, of questionable shock rating, require diesels to operate within narrow performance envelopes [4, 5], and, most critically, usually have substantial, heavy components installed in the upper levels of the ship – meaning adverse effects upon stability and the surrender of irreplaceable surface combatant top weight margins. These are the very surface combatant design margins which are prized for the installation of weapons and sensors – ie. combat capability systems.

Noting that there are 80 000+ registered merchant ships in the global fleet, compared with about 600 or so surface combatants (frigates, destroyers, cruisers) in commission in the world's navies, it is easy to determine that merchant ships as a source of NO_x form the core of the IMO's concerns. Consider also, that the Tier II configured surface combatant running on diesel would emit around 20 kg to 50 kg per hour of NO_x, while the Tier III merchant ships sailing past her, ostensibly with more admirable 'environmental credentials', would each be emitting anything from 100 kg to 200 kg per hour due to their larger, low speed diesels [6]. On an airshed scale, the additional NO_x emissions from a non-Tier III warship would be inconsequential, and disproportionate to the 'public cost' from forfeiting irreplaceable combat capability.

This is a patent example of a compliance technology imposing inordinate design and operational penalties for a combatant warship with minimal environmental benefit. Adoption of SCR NO_x emission control systems inescapably adds cost and complexity to warship design, operation and sustainment, for nothing more than intangible, inconsequential and ephemeral reductions in NO_x emissions, against the permanent and substantial surrender of irreplaceable and precious top weight margins. These considerations should tilt the balance sheet towards non-adoption by warships, given that this technology provides minimal benefit but at the cost of combat capability – the actual reason for the substantial public investment in the ship.

Alternative technical means more consistent with warship requirements and operating parameters are available if desired to reduce NO_x, albeit more expensive. This is arguably preferable than ‘making do’ with incongruous and unwieldy merchant ship technologies entailing inordinate and disproportionate penalties for nugatory and illusory environmental benefit, but questionable whether it is worth the financial cost.

Inane Technology: Exotic Fuels and Other Energy Efficiency Initiatives

The international shipping community is seeking to reduce the rate of greenhouse gas emissions from ships per tonne of cargo per unit of distance carried. One of the main routes through which this is being achieved is by the derivation and implementation of incrementally more stringent energy efficiency standards for ships. These energy efficiency goals are being realised by a number of planned or proposed or implied means including, *inter alia*:

- Ship propulsive power limitations
- Restrictions on ship operating speeds
- Use of novel and exotic fuels, including LNG, methane and blended fuels
- Use of sails

It is patently clear that imposing a 15 knot speed limit on a frigate, or restricting a destroyer’s available power to that required to barely make headway in a heavy seaway is untenable. In addition, the ship design complexities, not to mention the combat survivability hazards and afloat support penalties, inherent to any suggestion of using LNG, for example, should discount this fuel from any serious consideration for use in warships.

IMO energy efficiency aims, while sensible and apposite for merchant ships employed in the transfer of cargo from one geographic location to another, bear little relation to the operating requirements and typical taskings of warships, and not even to afloat support ships, the closest equivalent to merchant ships. Support ships are required to have the capability to loiter, 'sprint' as necessary, and undertake the full range of manoeuvre required of warships for operational and exercise purposes, and rarely sail directly between two points. By extension, any application of the full gamut of IMO ship energy efficiency requirements to a warship of any sort is inappropriate and nonsensical, at best. This is not to suggest that warships should not seek to optimise energy use, if for no other reasons as a means of enhancing endurance for any given amount of fuel, but the objective of adherence to IMO energy efficiency requirements is patently an absurd proposition.

Clearly, implementation of IMO promoted energy efficiency measures would result in the application of technologies to warships which would be inane at best, drastically limiting combat capability while significantly compromising ship lethality and survivability and operational utility. This is another example of where the rational adoption of sensible energy efficiency technologies in warships, while not necessarily implementing the IMO's prescriptions, would result in a 'fit-for-purpose' solution which is superior and eminently more preferable to the superficially 'perfect' technological solution.

SUMMARY

This paper has shown reasoning that contradicts extant navy policies which advocate 'full compliance' with IMO marine environment protection rules, without distinction. The real capability of a warship, whether expressed in anger during conflict or in peacetime deployments, is linked with its credibility as a capable friend or adversary in its designated warfighting role. All else is secondary to that, except to the extent that it may enable the primary function. While responsible management of environmental risks and compliance obligations is important, it is not, nor should it be, as critical a consideration as are those facets related to lethality, survivability, endurance, and signature. Accordingly, questions of ship design and equipment fit purely for the purposes of environmental compliance, especially if the risk to the environment from that platform is inconsequential, should never usurp the pursuit of optimising a ship's operational effectiveness and lethality.

There are many examples where myopic adoption by warships of technologies intended for merchant ships will incur penalties which are totally disproportionate to the actual risks, address risks which have little if any relevance to the warship, or which actually accentuate or introduce risks to the environment – the very thing which they are supposed to avoid. Furthermore, it is difficult to justify the adoption of technologies where not only are the actual risks to the environment modest, but where such adoption will incur significant penalties in ship combat capability – the whole reason why the warship exists.

Technologies developed for and focused upon merchant ships – and their typical design and build processes, ship characteristics and operating profiles – often have no sensible or reasonable application to warships. The unalloyed adoption of unsuitable technologies simply on the basis of 'this is what is used in merchant ships' does not withstand scrutiny on any level - legal, technical, operational or in terms of ameliorating actual environmental risks.

In many circumstances, the adoption by warships of alternative, parallel technological solutions represents a more responsible and balanced approach to environmental management than default adoption of the wrong technology. It is inarguable that achieving an outcome which is mostly right more often, is better than adopting an externally imposed, but inappropriate solution that may appear to be correct on paper, but which rarely, if ever, actually works properly. Adoption of the wrong technology for a specific application - use in a warship - not envisioned for that technology and which fails to address the intended purpose represents a folly. This is more the case when the actual risks to the environment, real or imagined, are not addressed and especially when any such risks are compounded and amplified. This is indefensible when such misguided endeavours also disproportionately detract from the combat capability of the subject ship.

The technological solution which works ‘well enough’ most of the time is eminently preferable to the wrong technology which rarely, if ever, works properly in the warship context. The warship designer should always seek the technology which works ‘near enough’ while simultaneously being compatible with warship design and operational imperatives, rather than simply adopting the superficially ‘perfect’ technology borrowed from others when such technology is not fit-for-purpose.

In the warship paradigm of limited space and weight availability and other design and operational constraints, ‘near enough’ is usually more than good enough when managing risks to the environment, even if short of what some may promote as a ‘perfect’ solution. Preference should be given in any warship ‘trade space’ to those modifications which will enhance operational effectiveness, rather than those focused solely upon limiting already minimal environmental risks, and especially not those done simply for a policy pursuit of ‘black letter’ compliance with a rule in the absence of any tangible risk to the environment. In essence ‘near enough’ in the warship design context can be expressed as ‘fit-for-purpose’, which is what all warship designs should strive for.

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