Instead of Simply Asking 'What?', Naval Engineers Need to Ask 'Why?': Environmental Compliance Challenges and Relevance in Warship Design

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Synopsis

Navies perceive benefit from proclaiming the intent to acquire 'fully environmentally compliant' warships, but such statements indicate minimal understanding of what is entailed, or realisation of the emasculation of ships' operational effectiveness inherent to such ambition. Inescapable technical realities further void any possibility of achieving this aspiration in all but limited circumstances. Navies need to be smarter in objectively characterising and managing environmental risks, and innovative in generating bespoke technical solutions.

Compliance with International Maritime Organization (IMO) marine environment protection obligations can be exceptionally onerous for warships, and in many cases nonsensical to pursue and arguably impossible to achieve. It is also ever more divergent from the standard caveat of 'not impairing the operations or operational capabilities of such ships'. Extant, emergent and forecast regulations address matters such as fuel consumption, speed limits, fuel tank protection, and ship materials. Some requirements can be accommodated, offering benefits in terms of operational effectiveness and sustainment. Many, however, cannot be addressed without penalty in combat capability, survivability and through-life costs.

IMO rules are founded upon merchant ship risks and linked merchant ship solutions; strict application of merchant ship risk remedies to warships can result in inappropriate design responses to ill-defined, inconsequential or non-existent risks. The design and acquisition processes of warships are also incompatible with IMO implementation schedules. Myopic application to warships of IMO prescripts can result in perverse outcomes which actually amplify risks to the environment.

Novel ways in which to demonstrate effective compliance with the intent of rules need to be adopted. Sensible environment protection should remain a policy goal, but implementation should only be on an innovative, judicious, and risk-assessed basis if warships are to accentuate operational capabilities, which, axiomatically is the base reason for their existence.

It is incumbent upon navies to also manage wider regulatory and policy dimensions. This can only be achieved by generating a clear understanding of what compliance entails in terms of capability and technical risks and how this may relate to a navy's core mission — to fight and win at sea. This must then be communicated as a cogent and reasoned argument to regulators and policy makers. This is so that commitments by navies to 'environmentally compliant warships' are neither arbitrary nor to the detriment of capability.

Keywords: IMO/environmental compliance; environmental risks; operational capability; alternative means of compliance; technical risk; risk evaluation

1. Introduction: Horses for courses — warships are not merchant ships

The international community, chiefly via the International Maritime Organization (IMO), recognises the myriad threats from shipping to the environmental quality and biodiversity of the world's oceans. Accordingly, the IMO has introduced controls on multiple aspects of ship design and operation, spanning the ship life spectrum from design to disposal. These rules, as reflected in parallel national legislation and Classification Society rules, are in constant flux, as the IMO deals with emerging Marine Environment Protection (MEP) priorities or exploits opportunities presented by evolving technologies.

Ideally, warships would comply with extant MEP rules without detriment. Technical limitations, design complexities, legal ambiguities and operational imperatives relegate such aspiration as virtually impossible to achieve, tempered by the fact that warships are different to merchant ships, and present different environmental risks than the ships for which the rules are formulated and intended. Furthermore, warships have no capacity to 'trade' capability for MEP, unlike merchant ships which can substitute lost carrying capacity for increased unit revenue. These realities compel navies to critically examine means of compliance with MEP rules, focusing upon risk management and innovation.

Observation of MEP measures by warships is not mandatory. In many aspects, compliance is relatively simple, unavoidable or makes good sense for capability or through-life support, with parallel benefits to the environment and public reputation. For example, minimising garbage by reducing stores wastage can extend endurance, as can

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optimising fuel use. In other cases, non-compliance is effectively not an option, an example being non-availability of ozone depleting substances, where even if desired, sourcing would be difficult in the absence of supply.

Most navies extol a policy of MEP compliance, or at least to the 'extent practicable' – something rarely defined. Warship compliance was relatively straightforward when navies adopted these policies. Over time, however, the span, penetration and complexity of rules have amplified while policy has stagnated; complete warship observation is onerous, and in some circumstances of minimal, if any, merit. In some cases, strict adherence is incompatible with a warship's *raison d'être*, to fight and win (and survive) at sea. This compels navies to evolve an agile, nuanced, risk-informed approach, applying lateral thinking to develop innovative, fit-for-purpose solutions.

2. As clear as mud: 'Legal' compliance for a warship

Navy compliance with MEP rules is often cited as a 'legal' obligation, but analysis can support an argument for totally ignoring rules, or generate a confusing morass of nebulous obligations. Notwithstanding the flexibility afforded within IMO MEP conventions for warship compliance, there are no clear, consistent mechanisms for application to warships.

The IMO deems assignment of nominated rules to any particular ship on a number of factors, typically expressed, *inter alia*, as:

- size of ship (typically defined in terms of GT);
- date of build;
- date of delivery;
- date of installation; or
- date of delivery for installation.

While some posit 'legal compliance' as irrefutable, warship 'compliance' defies meaningful definition. For example, should an individual warship, or class, be 'compliant' according to regulations extant at the date of:

- design finalisation?;
- contract?;
- laying down the lead ship or each individual ship?;
- commissioning (i.e. 'delivery') of the lead ship or each individual ship?;
- delivery for installation for the lead ship or each individual ship?

Some rules relate to gross tonnage (GT), such as ships of 400 GT and above are required to have an International Energy Efficiency Certificate, and ships of 5000 GT and above need to report fuel consumption. GT is a dimensionless representation of volume of a ship's enclosed spaces and is, broadly speaking, used as a metric to indicate carrying (i.e. revenue earning) capacity. Despite the word 'tonnage', GT has no relationship with displacement or mass. Although GT can be assessed for warships, such evaluation has no statutory basis. GT is calculated according to the *International Convention on Tonnage Measurement of Ships, 1969*, which states in Article 4 (1) (a) '*The present Convention shall not apply to ..... ships of war*'. Thus, the status of application of rules based upon GT to any warship is, by legal definition, somewhat opaque.

Legal vagaries aside, there should be no suggestion that warships exploit ambiguities as a shield to avoid responsible environmental management. Rather, this illustrates the nuances and obscurities attendant to any statement that warships will be 'legally compliant'.

3. Chasing one's tail: The dynamic rules base in relation to warship design and build processes

The IMO, by policy and precedent, focuses upon civil shipping: rules, and their derivatives, are of, for and about merchant ships, their risks and means of management. There are multitudinous reasons why many of these rules need not, nor can effectively, be applied to warships.

The IMO deliberates on MEP issues through the Marine Environment Protection Committee (MEPC), which meets once or twice per year; rules are consequently changed once or twice annually, with precipitate alterations in national and Class regulations. New and amended rules span the range from the profound to the pedestrian – establishing fundamental parameters for the general layout of ships, to minutiae 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 (Figure 1). Note that a new design / new build merchant ship is completed before the new rule enters force.

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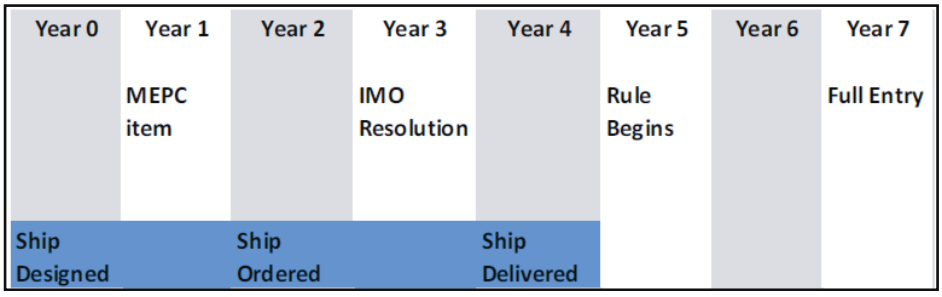

Figure 1: IMO MEP Rule Change Timeframes in Relation to Design/Build of a New Merchant Ship

Merchant ship timeframes are incongruent with the gestation periods for warships, particularly combatants, with lead times and build programs measured in decades. This has ramifications for achieving compliance during design and acquisition, and maintaining currency through life-of-type. Over the warship design and build period many new MEP rules will emerge, with these nominally applicable to individual ships in a class. Pictorial representation of the application of new rules to a representative four unit class of frigates, compared with that of a (conservatively extended) merchant ship design/build, is presented in Figure 2.

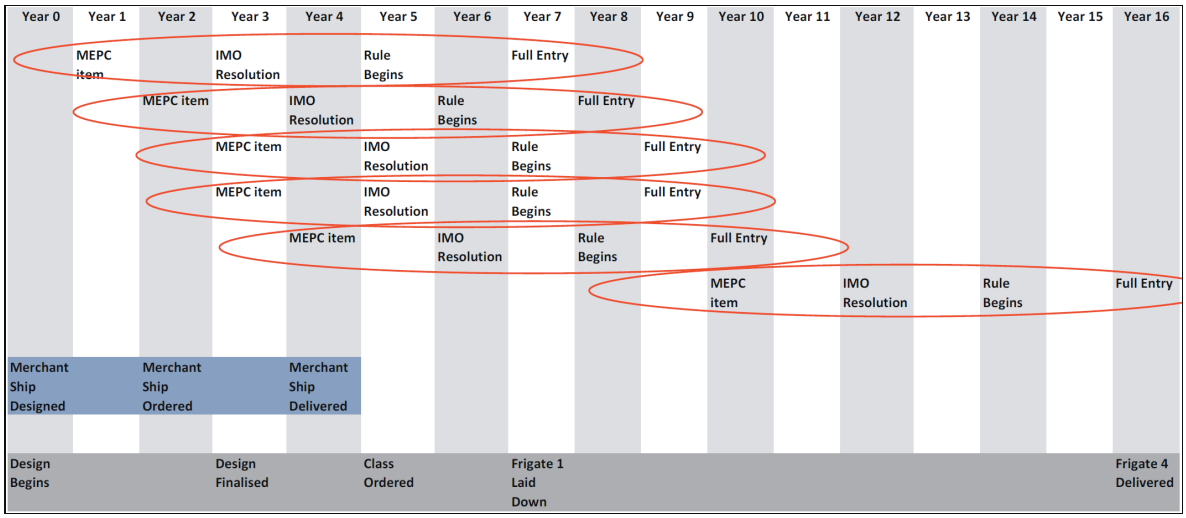

Figure 2: IMO MEP Rule Change Timeframes in Relation to Design/Build of a Four Ship Class of Frigates (*cf* merchant ship)

MEP rules display constant 'churn', becoming more expansive and elaborate, simultaneous with an increasing rate of promulgation and amendment. In its first 50 meetings, from 1974 to 2003, the MEPC issued 114 Resolutions, averaging around four per annum. Its next 21 meetings spawned a further 181 Resolutions, averaging around 13 per annum. This indicates the perpetual state of flux of the MEP rule set and its accelerating rate of change. Over a warship design/build program, typically spanning 15 years or more, it is reasonable to assume that rule changes would number in the range of 100 to 150 or more. Not all would have direct relevance but all would need review and analysis. It is difficult to comprehend how a class of warships in build could maintain alignment with a dynamic rule set. Furthermore, it is questionable whether the benefits would be worth the penalties for what may be nothing more than incremental or inconsequential environmental gains.

Even if a lead ship was, hypothetically, fully compliant with applicable MEP rules during build, the likelihood of retaining this status across sisterships is exceptionally unlikely, particularly with more complex designs and lengthy build programs. Some amelioration of inevitable obsolescence can be achieved by forecasting more stringent future requirements (introducing other risks, and assuming suitable technologies are available and proven). Furthermore, some warship types (e.g. oilers, 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 (e.g. submarines, destroyers, frigates). Ship upgrades and technology insertions provide capacity to regain some level of compliance, but the inevitable trend would be of divergence between the nominal rules baseline and individual ship compliance as the build progressed (Figure 3).

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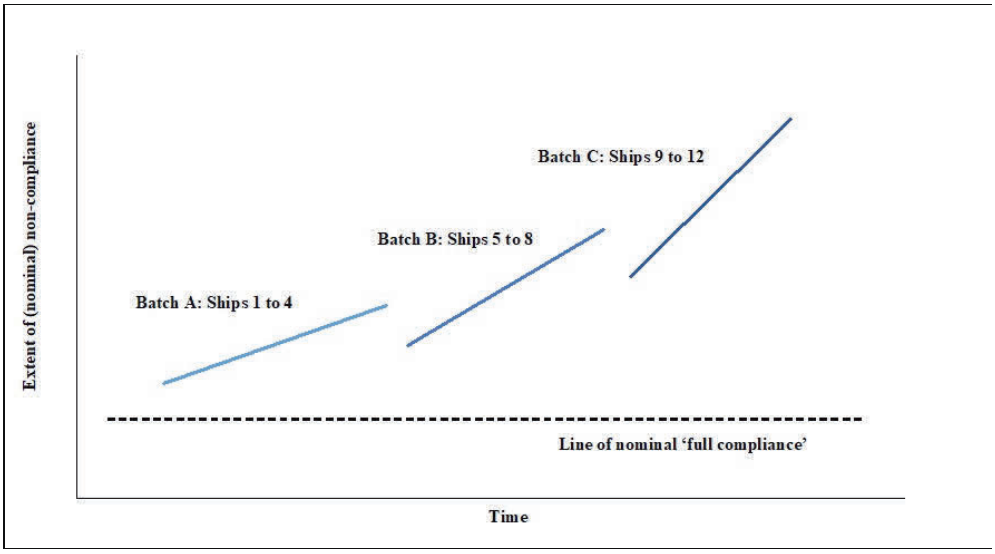

Figure 3: Indicative Trend and Extent of (Nominal) Non-Compliance Over Time of Three Batch/12 Unit Warship Class With Extant MEP Rule Set

Recognising and accepting these facts provides navies with the opportunity to articulate and characterise this 'built-in' non-compliance of warships. This furnishes both foundation and leverage to forge a more rational MEP risk and compliance approach, balanced with optimising the investment in capability made by governments and, ultimately, taxpayers.

4. There is more than one way to skin a cat: Understanding the risks and developing one's own remedies

IMO conventions address ship-sourced pollution in a variety of ways. The IMO does not, however, expect these rules to be strictly applied to warships, as all of its MEP conventions provide 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 also generally permit employment of exemptions and waivers when compliance would be 'unreasonable or impracticable', as well as equivalent means of compliance.

Two things are obvious from the IMO rules. The first is that the IMO accepts that warships cannot and should not always comply strictly with MEP rules. Secondly, is latitude 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 fundamental rationale of any MEP rule is not for ships to follow the rule, *per se*, but for the environment to be protected from the subject risk. This rationality lends itself to focus upon achieving goal-based outcomes, via alternative compliance measures if necessary (see Appendix A). Hence, rather than simply regurgitating the rule set in all cases, it is more useful to consider an MEP rule's objectives.

Focus upon objective, goal-based outcomes (the 'why') provides a vehicle for critical analysis of warship risks and means for their management. This in-turn underpins the observation of standard MEP rules where warranted and practicable, and the development of bespoke, and if necessary, innovative compliance models.

Many rules can be applied to warships without detriment, while others cannot and/or make little sense. If, on the basis of rational, objective and informed risk analysis, it is determined that a warship cannot apply a particular rule but still needs to manage associated risks, scope exists to adopt tailored risk reduction measures. An example of an MEP rule which has objective merit, but little realistic expectation of practicable application to a frigate or destroyer without '*impairing ... operations or operational capabilities*', is protected fuel tanks.

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4.1. Protected fuel tanks

IMO rules require ships designed to carry 600 m^3 or more of fuel oil to have 'protected tanks', typically achieved by the IMO-prescribed solution of double-hulling around tanks. This can be relatively easily accomplished in simple, invariably slab-sided merchant ships, which due to design and operating characteristics have historically shown to experience loss of fuel in the event of collision or grounding. These ships hence acted as the catalyst for IMO action on this issue, and the lens for the resultant rules.

In contrast, warships have features of design, manoeuvrability, crewing and fuel types which minimise the chance of such casualty in the first instance, and lessen the likelihood, extent and consequence of any ensuing fuel loss (see Appendix B). Furthermore, the hull projections on warships (e.g. sonar dome, stabilisers, propeller/s, rudder/s) act as a 'virtual double-hull' compared with the flat bottom, slab sides and absence of projections characteristic of merchant ships (Figures 4 and 5); this is borne out in the record of warship collisions and groundings, where the projection is often the point of contact[1].

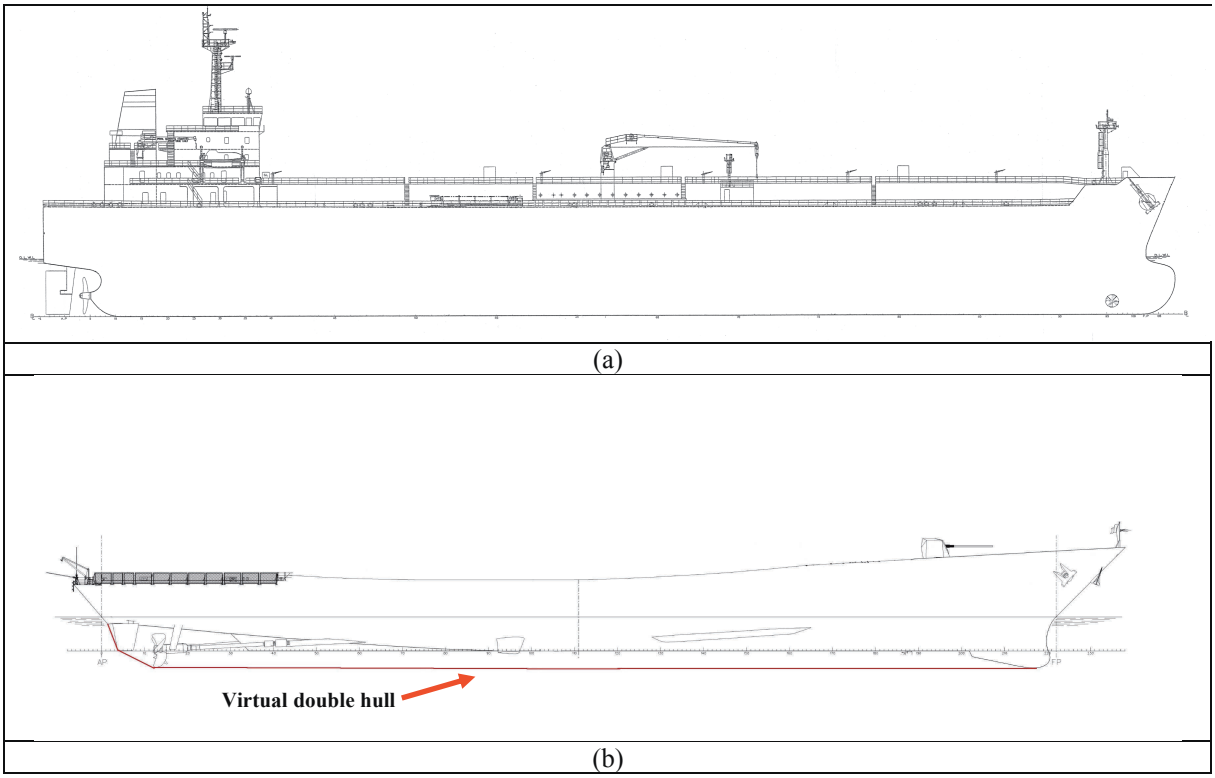

Figure 4: Comparison of Profile of Typical Merchant Ship Hull (a) With Surface Combatant (b) (note uniform baseline of merchant hull and the absence of projections)

[1] This conclusion is on the basis of analyses conducted by the author for a warship design project and contained in an internal report for that project (Polglaze 2009, *Air Warfare Destroyer Environmental Compliance Issues Report: Protected Fuel Tanks*). This report is not available in the public domain.

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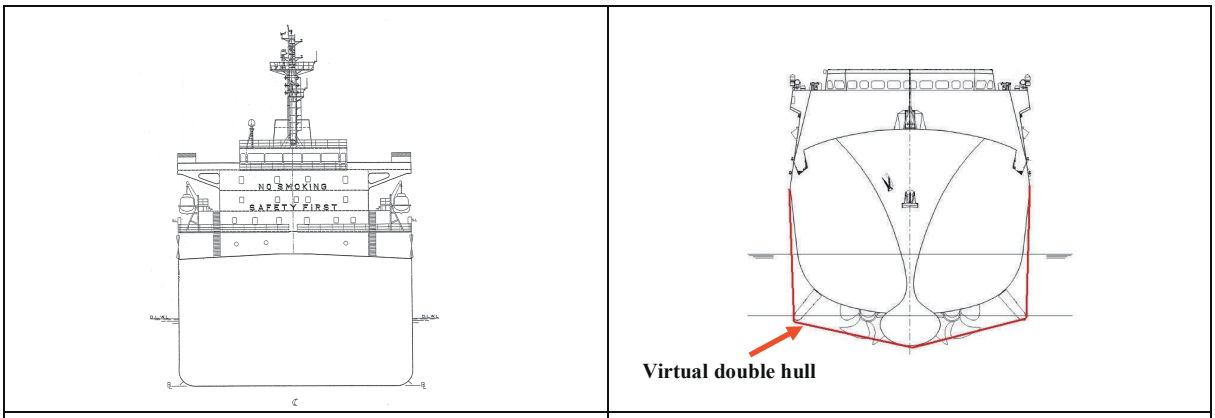

(a) (b)

Figure 5: Comparison of Cross-Sections of Typical Merchant Ship (a) With Surface Combatant (b)

Double-hulling in a merchant ship may result in loss of cargo capacity, but this can be offset by designing for larger holds or increasing unit costs to maintain revenue. In a 'space-poor' warship, any loss of space 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 rule via the oil outflow performance models, founded upon merchant ship risk factors, derives similar outcomes. Any attempt to comply in the design of a surface combatant with the IMO canon on protected tanks, never intended for warships, results in diminution of capability and survivability. Clearly, emasculation of warship potency is counter to the whole rationale of a warship. Adopting the IMO design measure would generate an aberration, likely increasing the chance of oil loss in the event that the ship is damaged or sunk in combat owing to reduced capability – the intrinsic contradiction of protecting the tanks at the expense of protecting the ship!

A further consideration is that the most frequent cause of the release of fuel from warships is due to refuelling and tank transfers (URS 2002). 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 fuel losses. Thus, application of a rule not intended for warships, inappropriately addressing an item of minimal risk, *would result in increased risk to the environment*, in parallel with compromising a warship's operational effectiveness. This is an irredeemably perverse outcome.

These realities should serve as a catalyst for developing innovative and bespoke alternative measures more fit-for-purpose. Similar, or indeed enhanced, levels of protection may be achieved by means such as strengthening hull plate and frames in key locations, rapid tank-stripping systems, refining tank arrangements, or sub-dividing tank extremities — all of which could be achieved with minimal, if any, detriment to '*operations or operational capabilities*'.

The protected tanks rule is a particular example where superficial appraisal leading to precipitate, dogmatic application of ill-focused IMO standards could result in a warship severely compromised in her ability to fulfil her fundamental purpose, ironically while simultaneously increasing risks to the environment.

4.2. Tier III NO_x emissions

Evaluation of Tier III nitrogen oxides (NO_x) regulations applying to diesel engines provides another example where rational analysis provides latitude for consideration of warship compliance penalties in the context of comparative risk. The Tier III urea-mediated control systems occupy valuable space, are expensive, of questionable shock rating, require diesels to operate within narrow performance envelopes (Fenske 2012; Laird et. 2016), and, perhaps most critically, usually have substantial components installed in the upper levels of the ship – meaning surrender of irreplaceable top weight margins.

If desired to reduce NO_x, alternative means more consistent with warship requirements and operating parameters are available, albeit more expensive. This is arguably preferable than 'making do' with inappropriate merchant ship technologies, but questionable whether it is worth the cost.

Holistic appraisal of 'ship lifecycle' emissions provides an illuminating perspective on warship compliance. Consider that a warship may be typically underway at sea for around 120 days per year. Of that period, a combined diesel/gas turbine (e.g. CODOG) unit will spend around 20% on gas turbines only. Furthermore, warships usually average around one year in every five to two out of every seven in extended maintenance or upgrade.

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Consequently, a warship's main diesels would be used for something of the order of 20% of her total life. Compare this with a typical merchant ship, which follows a schedule featuring minimal periods of time not at sea, and with maintenance periods measured in no more than weeks per decade. In terms of operating profiles, the warship realises a 70% to 80% reduction in NO_x emissions over her life compared with an analogous merchant ship – the same order of magnitude as the difference between Tier II and Tier III, without the inherent design restrictions, costs, logistic support imposts and operational limitations – especially when considered that this equipment would only ever be required while the ship was operating diesels within a NO_x Emission Control Area, but the sacrifice of precious weight and space would be permanent.

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. 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.

4.3. Energy efficiency

In recent years the IMO has implemented a range of mandatory energy efficiency measures. IMO precepts for energy efficient shipping include:

- alternative fuels;
- proceeding by the most direct, optimal route between points of departure and arrival;
- proceeding at (constant) most economical speed;
- mandating maximum speeds; and
- engines suited and tuned for optimal, constant speed running with minimum margin of power reserves.

It is difficult to reconcile IMO energy efficiency measures with warship design requirements and operational taskings. By extension, application of the full gamut of IMO energy efficiency requirements to a warship is inappropriate and illogical, at best. It is not suggested that warships should not optimise energy use, if for no other reason as a means of enhancing endurance (and capability), but any objective of adherence to IMO energy efficiency rules is arguably a futile proposition.

4.4. Summary

These examples reinforce the merit and utility of considering risks to the environment by warships from the perspective of the warship as the source of such (perceived) risk. The IMO has granted license for navies to assess risks and potential remedies in the context of warship design and operations, and to develop innovative solutions. It is incumbent upon navies to work within these 'domains' of compliance, across the technical, operational and policy realms, to objectively characterise risks and to adopt solutions, bespoke or orthodox, to manage actual risks, and not simply replicate prescriptive, ill-focused rule sets.

5. Beauty is in the eye of the beholder: Policy dimensions

Mansell and Tsamenyi (2012) opined ' …. IMO Conventions provide an appropriate standard for all ships, including warships, and … it is reasonable for Governments to apply these standards to warships where practicable' (author's emphasis). Simple to express, difficult to define and implement.

Navies are often obliged to adopt MEP rules by reason of government fiat or concerns about public reputation. Balanced appraisal of risks versus costs, as well as design realities, indicates many of these expectations are unfounded and unwarranted. This introduces another dimension of risk for navies, which is that of unnecessary regulation resulting from misunderstanding — something only an informed, pro-active navy can counter.

When considering public perception issues, it is recognised that concern exists about real or perceived adverse effects upon government and/or navy reputation where a warship may potentially be considered by the public and/or media as not conforming with extant (merchant) ship MEP standards. While not discounting such apprehensions, an equal or greater risk to reputation may also arise if the operational effectiveness of a warship is compromised, and/or significant cost is incurred, simply to demonstrate adherence to potentially irrelevant, misplaced and/or incompatible standards.

Although much is made within defence organisations of 'reputation' and community expectation, this is largely based upon internal assessment and anecdote, rather than empirical analysis. A more pragmatic approach to allay external scrutiny would be to clearly and cogently summarise and communicate actual environmental risks arising from warships. This would be leavened with associated information on design and operations responses,

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compliance implications, alternative means of management and the resultant residual risk profile. Such a package of measures should provide reassurance to government, regulators and the public – the taxpayer – that an appropriate balance had been struck between fielding a cost-effective and credible military asset in the national interest, while mitigating any substantive or unacceptable risk to the environment.

In this context, one should also consider the design and operating features of warships furnishing environmental benefit, often existing long before any corresponding attention from the IMO or embrace by the commercial sector. Examples include early adoption of low sulphur fuels, reduced radiated underwater noise, and designs which minimise the likelihood and extent of fuel loss in the event of battle damage (or grounding/collision). Another example is 'cold ironing', a concept 'discovered' relatively recently and since enthusiastically promoted in the commercial sphere (MEM 2018) — something which navies have been employing as 'shore supply' with no fanfare for many decades. No specific latitude exists within the prism of orthodox regulatory processes for any 'credit' for these practices. Nevertheless, this reality could be leveraged to demonstrate that navies are not environmental pariahs, and that development and delivery of effective maritime capability is not incontrovertibly to the detriment of the environment.

This underlines the concept of balance in terms of warship capability *v* environmental compliance and risks. Some aspects of warship design and operation meet, or exceed, regulations or minimise risks in the absence of regulation, while other regulations cannot be sensibly applied and/or are irrelevant. This situation can be communicated to government, regulators and the public to demonstrate that navies need not strictly comply with extant MEP regulations, and that absence of strict compliance means neither unacceptable environmental risks nor an irresponsible attitude. If implemented properly this approach represents the optimal return on taxpayers' investment in maritime capability while delivering the best capability options for government.

6. Conclusion: Don't throw out the baby with the bath water

Warships exist for one reason – to fight and win at sea. A merchant ship owner encumbered with difficult MEP requirements ultimately has the expedient of charging more per unit of cargo for the same level of service, within the boundaries of market forces acting upon a 'level playing field'. No such compensatory mechanism operates for warships, and no navy should seek or expect a 'fair fight'. Loss of range, speed, sensor reach, or armaments cannot be readily compensated in any meaningful sense, so navies should be motivated to cogitate deeply upon the extent to which emasculation of operational effect is warranted in terms of managing environmental risks, or those that would ensue in the absence of collateral design and operational penalties – often, but not always, the clear answer is 'none'.

Despite misconceptions or protestations to the contrary, navies already apply rules as they see fit, and/or as technical limitations and operational imperatives permit. The spectre of 'full compliance' is a chimera. Navies, and the nations they protect, would be better served by explicitly acknowledging these facts and using this as a foundation for observing MEP rules in a disciplined manner consistent with operational requirements and technical realities. In parallel, it should be understood that legitimate, informed departure from strict adherence to MEP rules can be accomplished without any meaningful deleterious environmental imposts.

Practicable application of MEP goals should remain a policy endeavour for navies. Clearly, observation of some rules is incompatible with the primary purposes and requirements of warships. Implementation of MEP rules and their intent needs to be approached in a balanced, informed and judicious manner, employing innovative means as warranted to manage actual risks. The prevailing paradigm must be transformed to an objective 'outcomes based' approach; not one defaulting to reflexive strict adherence to prescriptive rules. Otherwise, there may come again the time that Beatty's ghost has reason to declare 'There seems to be something wrong with our bloody ships today'.

7. Acknowledgements

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9. Glossary of terms

ANEP: Allied Naval Engineering Publication

CODOG: Combined Diesel or Gas

GT: gross tonnage

HFO: heavy fuel oil

IMO: International Maritime Organization

MEP: Marine Environment Protection

MEPC: Marine Environment Protection Committee

RAS: Replenishment-at-Sea

Author’s Biography

John Polglaze, the Director of PGM Environment, has over 20 years’ experience as a maritime environmental consultant, following a 20 year Naval career with service in submarines and surface ships. As well as work for the IMO, other maritime regulators and commercial shipping, he has worked in warship environmental compliance for over 25 years. This experience spans an array of capabilities, including patrol vessels, combat support ships, amphibious platforms, major surface combatants and submarines.

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Appendix A: Application to Warships of the Concept of 'Reasonable and Practicable' MEP Compliance

Where strict compliance with IMO-derived MEP regulations can be achieved and done so in a manner which does not detract or compromise a ship's capability, then such compliance should be aimed for. Many of the benchmark regulations do not, however, neatly conform to such a framework, necessitating a more bespoke approach if sensible outcomes are to be realised.

While focusing upon regulatory compliance, the design, configuration and operation of warships should also take due cognisance of other MEP issues which are not founded upon regulatory triggers. For example, minimal compunction exists to manage greywater as at the time of preparation of this paper, and while no such rules may eventuate in the short to mid-term, the ability to treat this waste stream should be considered as prudent means of 'future-proofing'. Another example is that of biofouling, where effective control not only has environmental benefit, but can also enhance ship performance and maintainability, energy efficiency and tactical effectiveness.

A warship's MEP status is derived from and can be achieved via an interplaying mix of a number of factors, the key ones of which are:

- legal drivers based upon IMO-derived benchmarks;
- technical opportunities and limitations; and
- operational requirements and imperatives.

Furthermore, (benchmark) rules and prospective solutions need to be tested rigorously within the paradigm of 'reasonable and practicable'. Elements of such testing may include, *inter alia*:

- Operational effectiveness — will there be any compromise (or enhancement) of combat capability? This may be defined in terms of platform lethality and/or survivability (e.g. weapon load, speed/range/endurance [and RAS requirements], effects on sensors, signature, damaged stability, etc).
- Technical practicability — can the rule sensibly be applied to the ship/class in question? What are the technical risks? Are suitable technologies available and proven? Are there options for methods of alternative compliance?
- Cost and cost-effectiveness — what costs, both capital and through-life, may be accrued? This needs to consider costs and savings of both compliance and non-compliance.
- Outcomes — will implementation actually derive any substantive environmental benefit, or be neutral or antagonistic in terms of resultant risks?

In terms of application of the principle of 'reasonable and practicable', the evaluation of risks and implementation of controls, either prescribed or equivalent, should take into account and balance all relevant matters including:

- the likelihood of the risk concerned occurring;
- the degree of environmental harm that might result from the risk;
- the availability and suitability of ways to eliminate or minimise the risk; and
- after assessing the extent of the risk and the available ways of it being eliminated or minimised, the costs associated with this, including whether the cost is disproportionate to the risk.

From these conceptual foundations it should be possible to develop a suite of tailored MEP requirements for individual or classes of warships. These tailored MEP requirements should be outcome focused (i.e. 'goal-based'), related to the intent and objective of the underlying MEP rules, and not necessarily a list of 'black letter' stipulations based upon strict compliance. It is suggested that these should be expressed in over-arching, hierarchical terms of:

- Goals
- Functional Objectives
- Performance Requirements

Consequential MEP risk management solutions would span the ship design, fit, procedural and policy dimensions. Ultimately, the latitude provided within this compliance structure would promote the development and adoption of tailored, risk-based, fit-for-purpose MEP solutions, employing innovative means as available and warranted. These solutions would be capable of accommodating and balancing operational imperatives with technical limitations and opportunities, within the context of responsible environmental management.

This suggested framework is resonant with that developed for ANEP-77 in relation to warship compliance with the aims and objectives of SOLAS (James & McKay 2014). Thus, this process would populate a goal-based approach, consistent with the structure detailed in ANEP-77 (Figure A1).

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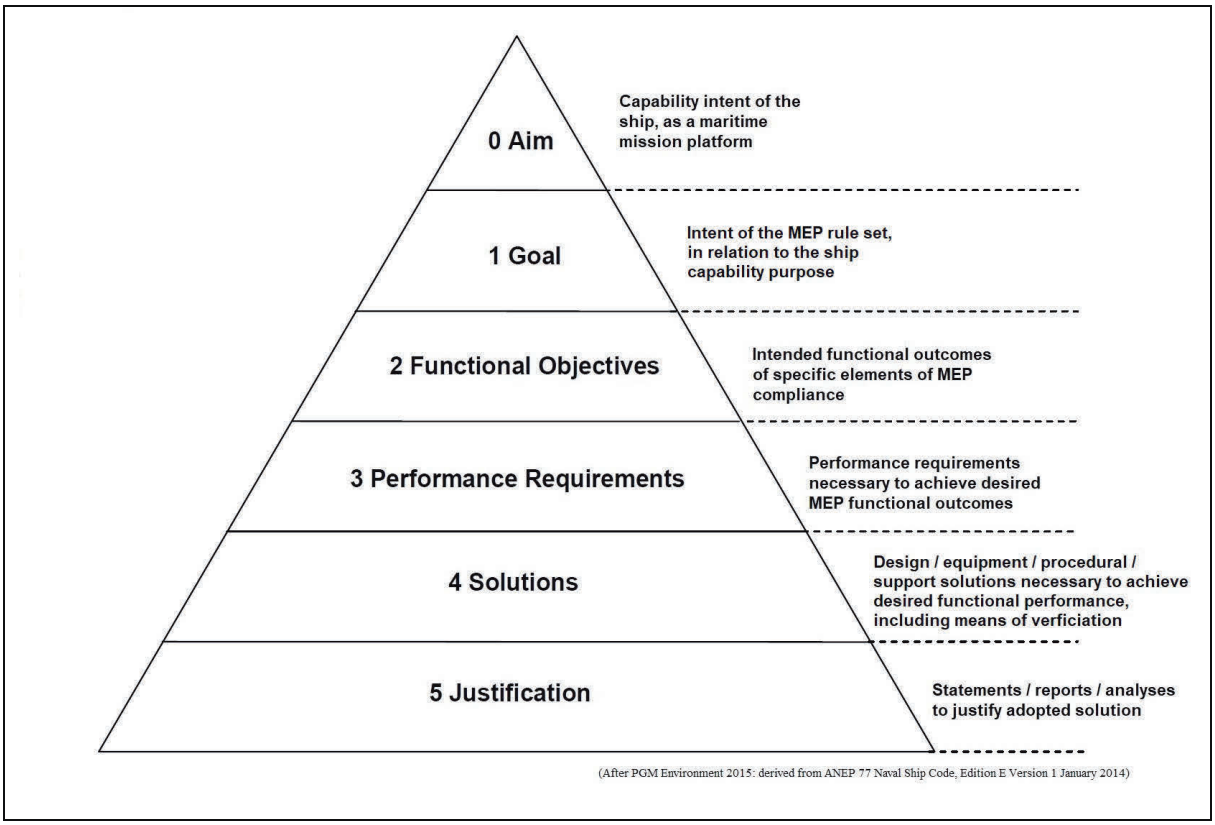

Figure A1: Hierarchical Goal-Based Approach to Developing Warship MEP Rules Set and Assessing Compliance Status

Appendix B: Ship Oil Fuel Spill Risks Considered to be Acceptable by the IMO

When assessing warships risks to the environment from the perspective of comparative risk, it is instructive to consider the oil spill risks that the IMO is willing to accept, albeit tacitly. Note that Regulation 12A of Annex I of MARPOL, which addresses fuel tank protection, is agnostic in terms of particular oil fuels, does not apply to ships with fuel capacities below 600 m^3, and permits individual tanks to be up to 2500 m^3. On this basis, it may be deduced that the IMO sees a spill of up to 600 m^3 of heavy fuel oil (HFO), a fuel type more damaging and persistent in the marine environment than diesel, as an acceptable risk.

In a study (APASA 2006) considering oil spill risks in a highly sensitive environment – the Great Barrier Reef – a range of spill scenarios were modelled. This included a 590 m^3 loss of HFO, as well as, in terms of a surface combatant, a more plausible, but still unlikely spill of around 200 m^3 of F-76 diesel (representing the largest individual tank in a typical destroyer) and, for comparative purposes, a similar size loss of HFO.

The modelling indicated results as follow for the given sea and weather conditions, and without any spill response intervention:

- The 200 m^3 F-76 spill would persist for less than seven days before evaporating, forming a slick with maximum extent of 34 km^2 that travelled around 39 km from the point of origin.
- The 200 m^3 spill of HFO would mix more readily into the water column and persist for more than 60 days (the limit of the modelling run), generating a slick in excess of 490 km^2 and displaced a distance of up to 270 km.
- The 590 m^3 HFO spill (deemed to be an acceptable risk by the IMO) mixed into the water column, and generated a slick in excess of 660 km^2 travelling over 270 km from the origin and still persisting beyond 60 days.

Arguably, in the modelled spill scenarios the risks to the environment presented by warship fuel were significantly less than those arising from merchant ship fuel, and thus of a lower order than the oil spill risks implicitly considered to be acceptable by the IMO.

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