MARINE DESIGN

REQUIREMENT ELUCIDATION
RATHER THAN
REQUIREMENT ENGINEERING

BY

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Introduction

The trend towards the use in Marine Design of the techniques of Systems Engineering was discussed by John van GRIETHUYSEN at IMDC 2000.[1] While he considered that the Systems Engineering approach could be of benefit in strengthening the engineering aspects in Project Management, he thought the approach, deriving as it did from the development of computer systems, had the risk of treating design as an abstract process with insufficient attention to the material features of the product. This risk is particularly manifested in the application of the technique of Systems Engineering termed 'Requirement Engineering', which is seen by its proponents as proceeding on the basis of a wholly functional statement of what the product is intended to do or provide – and to do so without the need to develop even an outline design description.[2] Much of the present author's experience is in naval ship design and therefore that is primarily used to illustrate the applicability of the article's theme to the whole field of marine design, for which naval ship design is a particularly suitable paradigm.

Taking as an example the acquisition of naval ships, it is possible to see the difference between the logic of the requirement drivers, expressed some two decades ago, for the Royal Navy's INVINCIBLE class carriers[3] and that for the new CVF. In the former case the requirement was regarded as emerging from the operational features of a complex mix of aircraft and ship based 'fight' capabilities, together with the constraints of the fleet's existing equipment and standards, as shown by (FIG.1); this still allowed the design team to produce a highly innovative and cost effective class of ships. In contrast, the CVFs as their replacements are said to have one overriding requirement, that of 'aircraft sortie generation rate', which appears to have emerged from the 'Requirement Engineering' process.[4]. A similar encapsulation of a major new warship class requirement appears to be the primacy of the Principal Anti Air Warfare Missile Systems (PAAMS) in the design of the Type 45 Destroyers[5] (though this may be just a headline, belying the extent to which the various elements of the ship's requirement have been derived and resolved in terms of their relative importance).

INFLUENCES	CONSTRAINTS
Submarine Threat. ASW Techniques. Air Threat. Area Air Defence. SEA HARRIER.	Existing Fleet. New Construction Programme Funding. Design Capacity (Inhouse – Extramural). Shipyard and Industry Capacity. Equipment Commonality. Ship and Weapon Equipment Development. Upkeep Philosophy.
Naval Staff Requirement.	INVINCIBLE Concept.

FIG 1 – INVINCIBLE REQUIREMENT EVOLUTION[3]

While many conventional merchant ships are produced without any equivalent comprehensive requirement derivation process, but rather are arrived at in response to a clear material statement from a potential owner. It is increasingly recognized that innovative design solutions are unlikely to be produced without consideration of the wider system within which the new ship or class of ships is to operate.[6, 7] This is clearly sensible if the ship or new class of ships is intended to be part of a larger (say containerised) transport system where the payload and delivery times are governed by the market or business needs. It is, however, less obvious when the ship is a service vessel, such as an offshore support ship, which provides a set of services at sea, often in response to unplanned contingencies. In requirement terms such service vessels are not unlike naval combatants intended to provide a military response to unplanned circumstances. WIJNOLST[7] examples the Wartsila *Seakey* approach from the former Kvaener Masa Yards as envisaging the ship design (in the **Seakey** example for that of a cruise superliner) as being at four levels:

1. *Mission*

   The basic business idea for the ship.

2. *System description*

   The functions of the vessel – payload, crew, machinery and other spaces.

3. *Product design*

   this starts by fitting the hull round the system level total, then the standard aspects of power, hydrostatics and stability and finally, a first layout is produced;

4. *Component design*

   A reasonably detailed weight and cost estimate is produced.

This process can be seen to readily lead into a design description which, with a cost, can be used to interact with the 'Mission' concept; in that regard it contrasts with the 'Requirement Engineering' approach while still having a system perspective.

The present article argues that the term Requirement Engineering, as adopted for naval ships to fit in with general military equipment acquisition, is both inept and misleading, and that the process of formulating requirements in Marine Design would be better described by the term Requirement Elucidation. The issue is not simply a semantic matter hinging on terminology, but rather one of procedural preference, in that Marine Design, when properly undertaken, involves an interactive relationship between a physical representation of the product and a developing evaluation of its capabilities; as indeed is suggested by the merchant ship example above. The importance of the topic for ship designers is illustrated by a, seeming, admonishment to past naval staffs as the custodians of naval ship staff requirements:

> "It has been said before, it is worth saying again: there are far more bad Staff Requirements than bad warship designs."
>
> PRESTON[8]

This observation does not in any way let the ship designer off the hook, the reason being that, as argued below, 'Requirement Elucidation' is, above all, a process which demands to be jointly undertaken by the requirement owner and the preliminary ship designer. Accordingly it is considered to be preferable to the current fashion (at least in the UK MoD[2]) for 'Requirements Engineering'. It is further relevant that the importance of this topic to ship designers is arguably greater than for the designers of other complex products, whether military systems or, say, commercial aircraft. This assertion stems directly from the fact that ships are designed, in the majority of cases, without the immense advantage of recourse to a prototype, which is tried and tested before production commences on the significant numbers of vehicles or equipment subsequently brought into service.

The article starts by reviewing Requirement Engineering from a Systems Engineering perspective and follows with a specific example of this practice which leads to a 'Functional Statement' of the User Requirement. The issue of what is the actual nature of a ship's requirement is then considered for a range of ship types and complexities. This in turn leads on to consideration as to how a ship design concept is arrived at, with the concluding section looking at why this process needs to be undertaken in a reasonably comprehensive manner, including a physical description, if the full range of issues are to be adequately addressed in a timely way for a proper elucidation of a ship's requirement.

As is usual in articles on Marine Design, the author refers in this article to 'the designer' in the singular, despite the fact that, because of the complexity and scale of the product being designed, the design processes involved call for a considerable multi-disciplinary team. The usage being justified on the grounds that the word designer can, for the purposes, be regarded as a collective noun. For the present article, however, as a consequence of the move by the UK MoD towards the earlier stages of the design of naval ships being undertaken competitively by contractors, there is a need to recognize that there can be different sorts of plurality associated with the design activity.

A rather similar point arises in the present article in connection with the use of the singular for the word 'requirement'; the usage issue arises in the present context because, for a complex multi-functional product like a naval ship, there is a multiplicity of particular requirements to be addressed by the design process. The convention is in effect to treat the term 'requirement' as if it were a plural noun.

Requirement Engineering – a Systems Engineering Perspective

Following the collapse of the Soviet Block the Western Powers have had to reassess both their collective and individual defence postures. A significant aspect of this reassessment relates to the acquisition of defence equipment, which constitutes a substantial element of those nations' government purchasing. Thus in the UK, as part of its Strategic Defence Review, the newly elected Labour

Government introduced a comprehensive restructuring of its defence equipment acquisition processes known as the Smart Procurement Initiative (SPI). SPI's intent was encapsulated by the phrase 'faster, cheaper, better' and an important step towards meeting those ends was seen to be in the move away from equipment based requirements.[9]

The very specific nature of the equipment-focused statements in the past of the defence staff's desires for the abilities required of new equipment is illustrated in the warship case by the Navy Board Directive issued to the procurement authority of the day for the Type 42 Destroyers, namely:

> "There should be no margins for future equipment."[10]

This clear mandate, from the Navy as the end customer, resulted in a design that has proved very expensive to upgrade, particularly in the enhancements seen to be essential following the Falklands War. The belated modification to the last batch of the class of a 10m hull lengthening revealed how such a rigid materially based injunction imposed on behalf of the operational customer led to a less than satisfactory design solution.

So among the aims of SPI was the provision of a clearer identification of who is the end customer for new military systems, together with the introduction of refined processes for such activities as equipment acquisition, researching technologies, managing procurement projects and supporting equipment through life.[11] There was a further commercially motivated imperative for the MoD, as a major customer of industry, in defining the requirement for new military systems without reference to specific equipment. The motivation for this approach was the belief that it clearly left the choice of the actual material solution, to meet the MoD's requirement, up to the finally selected contractor. This reasoning led to the further belief that the contractor could then be held liable for any failure to meet the requirement. Leaving aside the fact that for any major military equipment programme this approach had not hitherto been applied (and is virtually impossible for a major warship, representing as it does, an exemplar of the 'system of systems' and having a considerable legacy of systems, equipment and standards), it also carries the functional statement of the requirement to have an even greater onus placed on it to be unambiguous, than hitherto.

In pursuing its objectives SPI called for:

> "Focus on user needs rather than equipment characteristics."

This to be achieved through two sets of documents or data banks:

- The User Requirements Document (URD).
- The Systems Requirement Document (SRD).

These are functionally expressed and 'engineered' in the manner shown in (FIGs.2 and 3).[12]

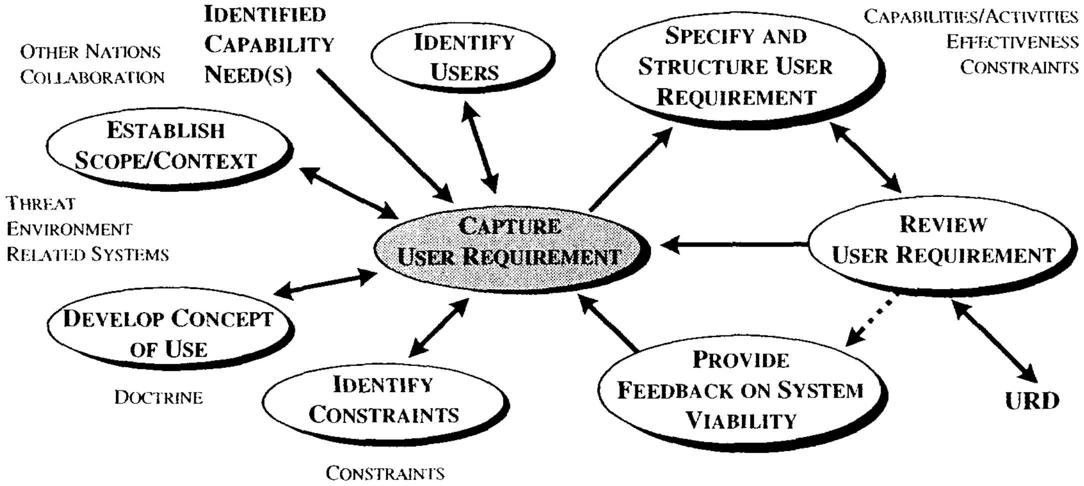

FIG 2 – ENGINEERING THE URD[12]

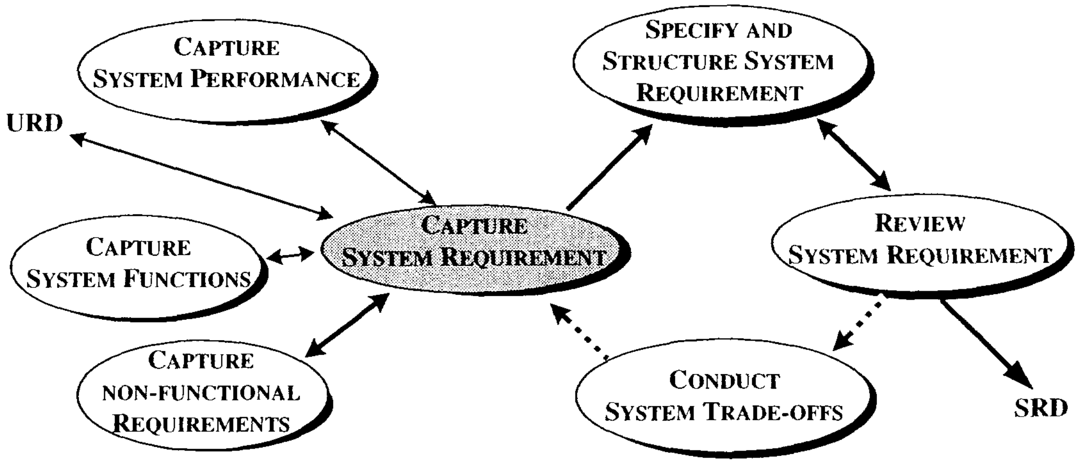

FIG.3 – ENGINEERING THE SRD[12]

The way in which this 'Requirement Engineering' is to be undertaken is shown in (FIG.4), the Requirement Process.

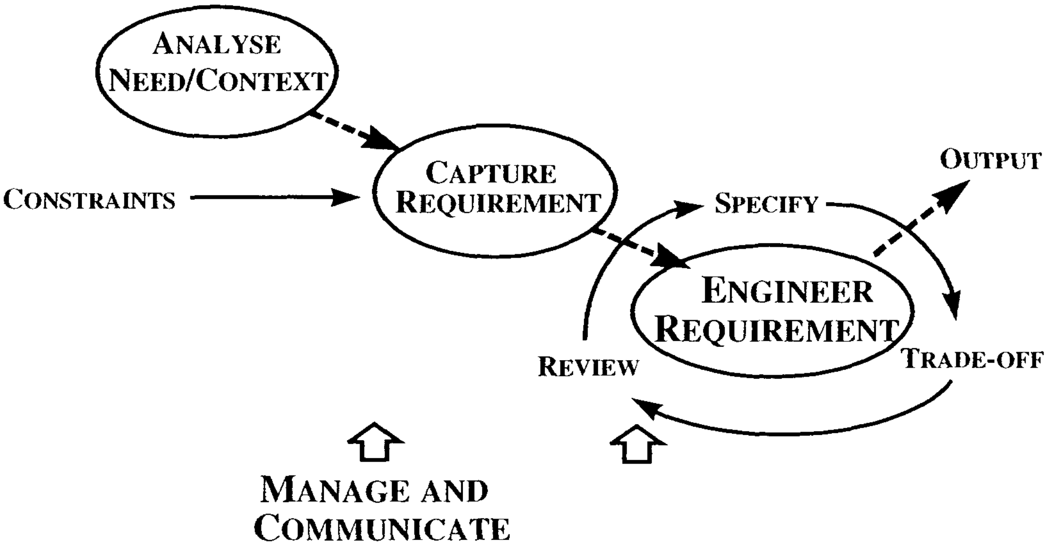

FIG.4 – THE REQUIREMENT PROCESS[12]

Analysis of the need derives from the wider (defence) mission, which is incidentally the same term as that used by WIJNOLST[7] for the ship's overall role for innovative merchant ship design. This then indicates the scope of the requirements, together with the external operational and development factors, and hence bounds the requirements. The requirement is captured from a wide range of sources, such as workshops with user groups and Operational Analysis (OA) studies, based on appropriate scenarios. Such scenarios are crucial and inevitably have to make use of the operational characteristics of existing and postulated equipment, including, importantly in complex maritime scenarios, naval combatants with their multirole capabilities – which can often be poorly modelled by OA.[13] It follows that the seemingly functional purity of the Requirements Engineering process, in assiduously avoiding any focus on material solutions, is in practice seriously flawed, at least in application to naval combatants.

An example of a Functional Requirement

As can be seen from the case of the INVINCIBLE class carriers described above, for any new class of major naval vessels it is unreasonable to think of the vessel's capability in isolation from the rest of the fleet's capability, and indeed of the fleet's support infrastructure and personnel aspects. The particular example of a functional requirement selected for consideration in the present context is that of the Future Surface Combatant (FSC), the next major class of warship for the Royal Navy.[14] The FSC was originally intended as a class of combatants replacing the substantial capability currently provided by the twenty or so ships of the Type 23 and Batch 3 Type 22 Frigate classes. The new class was renamed the FSC following the UK Government's Strategic Defence Review[9] in recognition of the move from sea control to an expeditionary defence doctrine. This policy led to a consideration that the FSC would require a capability for power projection, versatility, the ability to establish presence and exert a graduated military response, in addition to peace keeping and contributing to the fight against international terrorism.

As outlined by FINLAYSON and JOHNSTONE,[15] the FSC's requirement has been captured by identifying capability gaps, as shown in (FIG.5). Thus Capability

Area Plans have been produced from various sources, namely, High Level (i.e. strategic level) OA, the Defence Strategic Plan, analysis of Defence Capability, identifying current Capability Shortfalls and indeed the consequences of current equipment (e.g. ships) going out of service. Two further important inputs to this assessment of the relevant Capability Gaps are provided by 'Military Judgement' and 'future capability requirements', both of which are very difficult to undertake and virtually impossible so to do in a genuinely 'functional' (i.e. non material or solution specific) manner. The exercise leads to a list of capability gaps for inclusion in the FSC requirement.

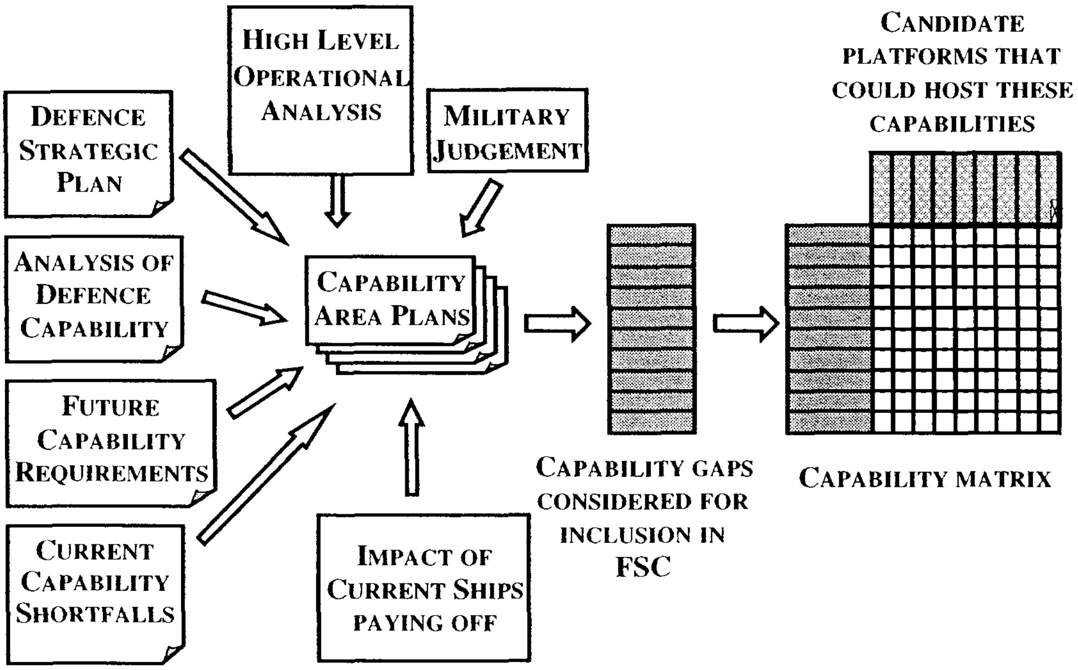

FIG.5 – DERIVING THE CAPABILITY GAPS FOR THE FSC[15]

The ship requirement starts at the top level with a Mission Statement, which states:

- What the operational objectives for the FSC are.
- Where it is intended that the FSC will militarily engage and against whom.
- When the engagements will take place and for how long.
- What is seen as the FSC's role in such engagements and how the FSC is intended to interact with other forces.

All these considerations lead to the Single Statement of Needs for the FSC shown in (FIG.6), together with, in the case of the FSC, seven High Level Characteristics (HLC) and twelve Key User Requirements (KUR), also listed in FIG.6. The former serve to cover not just obvious operational roles but also the more supportive or 'Enabling HLCs' of Survivability and Availability, while the KURs largely describe specific tasks (albeit at high level), with just KURs 9,10 and 11 having aspects of an enabling nature.

FUTURE SURFACE COMBATANT STATEMENT OF NEED

The FSC will exercise Maritime Presence worldwide operation either alone or as part of a force to enable graduated response. FSC will support land operations, especially early entry forces, through littoral manoeuvre. In the future multi-threat environment, it will contribute to the protection of sea lanes of Communication and deployed forces by providing specialist capabilities in Anti-Submarine warfare and Littoral Anti-Surface Warfare, supported by Anti-Air Warfare Point Defence. In so doing the FSC will provide an enduring contribution to national and multinational operations conducted from the sea.

FSC HIGH LEVEL CHARACTERISTICS

HLC 1 – Sea Control	HLC 2 – Littoral Manoeuvre	HLC 3 – Force Protection
HLC 4 – Wider Utility	HLC 5 – Interoperability	HLC 6 – Availability
HLC 7 - Survivability		

FSC KEY USER REQUIREMENTS

KUR 1 — Neutralize the effect of enemy underwater units that pose a threat to own forces sea control.
KUR 2 — Neutralize the effects of enemy surface units that pose a threat to own forces sea control.
KUR 3 — Destroy enemy units in support of tactical land operations.
KUR 4 — Deliver and extract early entry forces.
KUR 5 — Defend maritime force against hostile acts committed by underwater threats.
KUR 6 — Defend a maritime force against acts committed by surface threats.
KUR 7 — Arrest vessels during maritime interdiction operations.
KUR 8 — Exchange data with allied military units.
KUR 9 — Operate over the three Mandated Zones.
KUR 10 — Relocate inter-theatre.
KUR 11 — Readiness Profile.
KUR 12 — Operate in a threat environment.

FIG.6 - FSC STATEMENT OF NEED AND HLCS AND KURS[15]

Importantly the KURs are each assigned a specific Measure of Effectiveness, where effectiveness is not the same as performance (the measures of which are the more traditional means for the designer to assess the manner in which the design achieves its perceived requirement). (FIG.7) gives some related terms with short explanations of what each term means in the context of operational requirements.

Capability — The power of doing something.
Characteristic — The physical feature which distinguishes the object from a purely functional black box.
Sustainability — How long a capability persists.
Survivability — How much of a threat can be withstood.
Effectiveness — How well something is done. (The impact on the outside world).
Performance — How well something acts to give an output. (The technical measure of a thing).

FIG.7 – DEFINITIONS USED IN OPERATIONAL ANALYSIS

It is instructive to consider whether such an approach could be usefully applied to the merchant ship environment. As previously noted, WIJNOLST talks of missions for a new ship requirement but is clearly not talking in military geo-political terms but rather in terms of the business imperatives of a given commercial organization. The SEAKEY example he gives quickly breaks down into a clear material hierarchy, as outlined in the Introduction. Proponents of the non-material or functional 'Requirements Engineering' approach are likely to argue that this could lead to missed opportunities for radical market innovation, an argument which can be countered by the aspect that any commercial vessel has to be justified to potential investors as having a clearer (less multirole) capability than in the case of a class of warships. The issue is an important distinction in comparison to a major naval vessel, which in any case has a longer 'pay back' and a primary need to deal with extreme uncertainty.

This FSC example of the application of the 'Requirement Engineering' approach would appear to have the virtue of clarity of definition for the naval staff in their role of requirement generators and a response to the comment of PRESTON on Naval Staff Requirements quoted in the introduction. However, it has to question whether such an approach actually provides a better definition to the designer who has to produce the new artefact. And if this is not the case, then while the approach might give the requirement generators a sense of improved clarity, if it does not lead to better material solutions for the users of very complex artefacts, typified by the major naval combatant, then the substantial effort involved could be counter productive.

Scoping a Ship Requirement

For many years the nature of initial ship design has been characterized as a clear example of a 'wicked problem' in design,[16] namely, that the real problem in ship design is not the one usual in engineering product design of taking a prescriptive requirement for the product and applying specific algorithms to achieve the solution to that requirement;[17] rather, the ship design task is characterized by finding out what is the nature of the problem or requirement, for the designer as well as the requirement owner. In ship design terms it was characteristically pithily stated by Sir Rowland BAKER:[18]

> "Which comes first, the chicken or the egg? So the chicken comes before the egg and the ship comes before the staff requirement."

For this reason the wicked problem demands to be tackled through a dialogue between the requirements generator (the naval staff or ship owner) and the preliminary ship designer. The purpose of the dialogue is to elucidate the best mix of conflicting requirements within what is affordable and achievable, which necessarily has to be done by reference to materially feasible potential solutions. Hence the title of this paper, Requirement Elucidation.

Why is this considered to be so for ships in particular? It is not just because ships are complex – not just that they are produced without a prototype – nor even that the requirements are highly interdependent and interrelated. Rather it is because, primarily, the nature of a multirole ship is such that certain characteristics more strongly determine the size and cost of the total ship than is necessarily obvious from what seems to be the primary operational needs to the requirements owner. Thus the need to ensure the ship floats and resists the action of the waves, leads to the largest proportion of the ship's weight, while the need for mobility leads to the shape of the underwater form, constraining much of the engineering solution, and its interaction with the machinery constitutes another major size determinant. Yet another significant size determinant is the area devoted to personnel living onboard. All these factors constitute significant determinants of the eventual solution but do not figure explicitly in either the HLCs or the KURs in FIG.7, except by inference in a couple of cases – in effect they are taken for granted.

This would be all right if the designer, taking proper recourse to sensible preliminary ship design descriptions, is fully involved in the dialogue with the requirements generator. However, if the stance of Requirements Engineering is taken to necessitate that only functional statements of the user requirement are permissible then the material solution is relegated to a secondary role at best. The designer would in those circumstances be left just to provide inputs at the request of the requirement generator to inform cost estimates, and would no longer be an active partner in the elucidation of the wicked problem.

While the HLCs and KURs are useful in encapsulating the operational requirement, they present only a part of the picture in requirement elucidation. It is also mistaken for the 'enabling characteristics' to be regarded as no more than necessary embellishments on the 'real operational capabilities' required. To some extent this view has been fostered by the traditional ship weight breakdown structure on which preliminary cost estimates are largely based. (FIG.8), taken from a paper on warship costs,[19] illustrates the misguided impression that the ship is just an overhead on the combat suite – the platform/payload misapprehension.[20]

Group	Description	Weight (tonnes)	Cost (%)
1	Hull structure	800	14
2	Hull support	100	6
3	Hull outfit	150	8
4	Main machinery	500	23
5	Auxiliary machinery	250	18
6	Elect, Comms, Control	200	13
7	Armament	120	1
8	Variable items	700	
	Growth margin		
	Board margin		
	Displacement	**3000**	
9	Shipyard miscellaneous costs		16
	Ship cost		**100**
	Weapon equipment cost		30
	Contingency		16
	Initial Cost		**146**

FIG.8 – EXAMPLE OF FRIGATE WEIGHT AND COST BREAKDOWN EMPHASISING THE "PLATFORM/PAYLOAD" MISAPPREHENSION[19]

A better way to see the holistic nature of the total design is to use the Float- Move-Fight (or Operations in the case of a non-combatant or commercial service vessel) and Infrastructure breakdown (The paper on the SUBCON concept system[21] provides a justification for the addition of the Infrastructure category.). This approach not only shows the sensible balance of functions, in determining the eventual material solution, but also highlights the inter-relatedness of the component parts of the whole design. It is also relevant that there remains a difference between Fight/Operations and Float and Move elements, in that the latter do not have features/capabilities that can be readily deleted. Thus in Fight, for example, ASW or Land Attack could be deleted, if so desired, with the loss of a discrete capability within Fight. However, Float and Move are whole ship characteristics, which cannot be deleted – at best they can only be reduced in standard (in the case of Float) or demand (in the case of Move). In other words, they are holistic features of the ship and are not strictly amenable to the partitioning implied by the systems engineering hierarchy.

Moreover the Float-Move-Fight/Operations and Infrastructure breakdown also helps to emphasise that, while the user is likely to focus on the Fight/Operations element, what gives a ship its distinctiveness are the Float-Move-Infrastructure aspects, such as Mobility, Sustainability (including human support) and Survivability. The latter includes standards, such as signature levels which can be crucial to Float and Move features, together with contributing aspects, like human factors, fundamental to certain Fight capabilities. Thus for example adoption of external structural detailing above the waterline will greatly reduce the ship's radar cross section, thereby enhancing its point defence capability. If the mounting of machinery is designed to attenuate the noise levels transmitted into the water, then the delectability of the ship is reduced and its own ability to detect submarines improved. Both these features will increase the ship element of the cost and so might be considered to 'worsen' the 'platform/payload' ratio, when in fact they greatly enhance the military worth of the whole warship. It cannot be argued that all such significant cost drivers are not fundamental to the military worth of a naval combatant, and ought to be treated as mere add ons to the primary Fight capabilities. Rather such features need to be fully debated in the interest of elucidating the requirement and – given their intimate integration within the holistic entity of the naval combatant – need to be fully considered in the requirement elucidation. This outcome is only sensibly achievable if requirement derivation is undertaken in conjunction with the technical exploration of the whole ship, rather than just being driven by the partitioned functional URD structure arrived at through the inappropriate mindset represented by Requirement Engineering.

The above discussion has been largely related to the case of the Destroyer/Frigate combatant, to which the argument for a functional approach to requirement derivation has in some quarters been thought to be directly applicable. However, there are many other vessels, naval and commercial, where the design is driven by the need for physically large operational spaces (e.g. aircraft carriers, amphibious vessels, afloat support ships, offshore support vessels, cruise and large ferries). Often in these cases obtaining their initial sizing is far from straightforward, and the configurational arrangement rather than gross size is the overriding determinant. There is also the need in a comprehensively conducted ship acquisition process to undertake the Requirement Elucidation in a materially open manner, in such a way that the final form of the design is not closed off prematurely. Thus Unconventional Hull Forms (UHF) such as SWATH, Trimaran and variants, as well as high speed forms such as Surface Effect Ships (SES), hydrofoils and Hydrofoil Small Waterplane Area Single hull (HYSWAS) should be addressed. These novel forms do not fit simple size and cost algorithms; additionally, exploring such potential solutions can highlight that certain (seemingly) secondary requirements or standards can be major design determinants. This aspect further reinforces the need to adopt a material based approach to requirement derivation.

Producing a Ship Concept

The argument above brings out both the importance of and the high degree of sophistication involved in producing an initial ship concept. Although initial ship descriptions are quite often regarded as having the purpose of providing the means to achieve an initial feel for ship cost, as in FIG.8, they are customarily accorded the significant role depicted by the term concept study or concept design. This status is quite different from the usage adopted by the Operational Analysis specialists when referring to a new operational concept, be it a ship, combat system or tactical evolution; in that case it is the capability which the concept under consideration brings to the operational scenario that is the characteristic of prime importance to the analysis. While ship concept studies are accepted as being important to informing costing, this fails to take into account that it is because of the wicked nature of the design process and that the concept studies are essential to the conduct of the dialogue with the requirement generator, in order to achieve proper requirement elucidation, that the production of these sorts of studies is so vital.

In an attempt by the author to distinguish the technical or design focused task of the ship designer from the purely cost input to the OA concept work, a more structured description of the preliminary design process for naval combatants was outlined several years ago.[22] That paper hypothesised that the process entailed several overlapping stages, identified as Concept Exploration, Concept Studies and Concept Design. In summary, the first is an unconstrained exploration considering all the possible solutions, which for convenience could be considered to inhabit a three dimensional space of 'packaging', 'technology' and 'capability'. The Concept Studies stage that follows then takes on the insights provided from the first stage and focuses more on the factors already suggested to be significant design drivers. Through design studies, preferably of a architectural nature as described below, the above three dimensions and other likely discrete drivers can be studied for their effect on the whole ship and its intended performance; some of these drivers might be:

- Speed.
- Seakeeping.
- Endurance.
- Survivability.
- Logistic considerations.
- Style (e.g. adaptability, robustness and standards).

The final, Concept Design stage, is intended to produce a baseline design solution, which matches the evolving requirement and emerges from a trade-off analysis core to the Requirement Elucidation process. Another element of what is being termed Concept Design is a full investigation of the range of material options built on the first two stages, for the purpose of ensuring that radical technologies and whole vehicle solutions, that can markedly modify requirement perceptions, are fully considered and if necessary pursued in parallel with a more conventional option. A current example of the latter issue is the UK MoD's continued sponsorship of a Trimaran option for the FSC.[23] A less structured and, admittedly, less drawn out process could be possible in the merchant ship world; however, as remarked above, the more innovative approach called for by WILJNOST does look to decision support techniques to avoid adopting obvious design options without a thorough exploration of the material and operational alternatives.

The primary means to undertaking Requirement Elucidation is the identification of design drivers to enable the preliminary ship designer, in conjunction with the requirement owner, to:

- Inform the assessment of cost drivers for trade off studies in Capability Management.
- Better contribute to Requirement Definition.

There is also a need to establish whether more detailed analysis is required, even in the concept phase, because of the risk that the concept could be flawed. It can be believed by non-design participants in the earlier stages of procurement activities that ship designers unwittingly seek to pursue design to an excessive degree of detail. While there can be some truth in this, because of the aim of any engineer to minimize risk, there are sound reasons why in particular studies it may be necessary to go into some aspects to a level more normally adopted as part of the deeper Feasibility or Ship Design phases downstream from Concept Design. Thus, for example, in the preliminary studies for the new UK Auxiliary Oiler vessels, it was necessary to undertake a comprehensive damage stability analysis as part of the initial sizing of the concept because the design was the first naval oiler to have to meet double hull requirements. In another case, that of an auxiliary helicopter carrier, where its relatively slow speed and low demand for ordinance led to reduced internal volume requirements below the hangar level, comprehensive damage stability analysis was required to avoid the large undivided hangar deck breaching the 'Red Risk Waterline'. In both these instances considerable analysis, way beyond that normally required at the early stages of concept work, was necessary on a specific aspect which was appreciated as being a major size and cost driver. The point of this comment in the present context is that it serves to emphasise two important aspects.

Firstly

> In preliminary design the designer only goes to the minimum level of definition required, but in discrete areas that could be quite significant.

Secondly

> This reinforces the need to achieve a close working relationship between the requirement owner and the preliminary ship designer; thus 'black box' costing algorithms are dangerous as they can mislead the requirement owner about what is affordable or even what is achievable, and almost certainly will miss the innovative option.

The comment in the previous section on the need to explore alternative hull forms as part of the exploration of solutions can be reinforced by recognition that joint consideration of innovative solutions can lead to significant reassessments of the requirement. Despite the ambitions of the so-called functional approach to requirements derivation, the requirement owner is unlikely to contemplate selecting requirements which he 'knows' "cannot be achieved". This reluctance can be seen as a worse form of prejudging requirements than the currently perceived dangers of material dominated solutioning. Such statements as the ship is "too big" reveal a mind set that arises from affordability being (rightly) regarded as a major imperative and then being coupled with the crudity of most initial sizing and costing approaches, due to the dependency of initial ship cost estimates on relatively simple sizing estimates.[24] Such misjudgements occurred in the pre Requirements Engineering era but are now considered to be worse, given an approach that is thought to be 'rational' in its functional rather than solution driven logic. A good example of a circumstance in which a simplistic size argument was shown to be flawed is the case of the US Navy SWATH studies,[25] where an apparently equivalent ship to a SWATH frigate was 20% smaller in displacement than the SWATH, when sized on the same payload basis, and yet the real equivalent monohull (that is that design with the same seakeeping performance as the SWATH) was actually 30% larger than the SWATH (FIG.9).

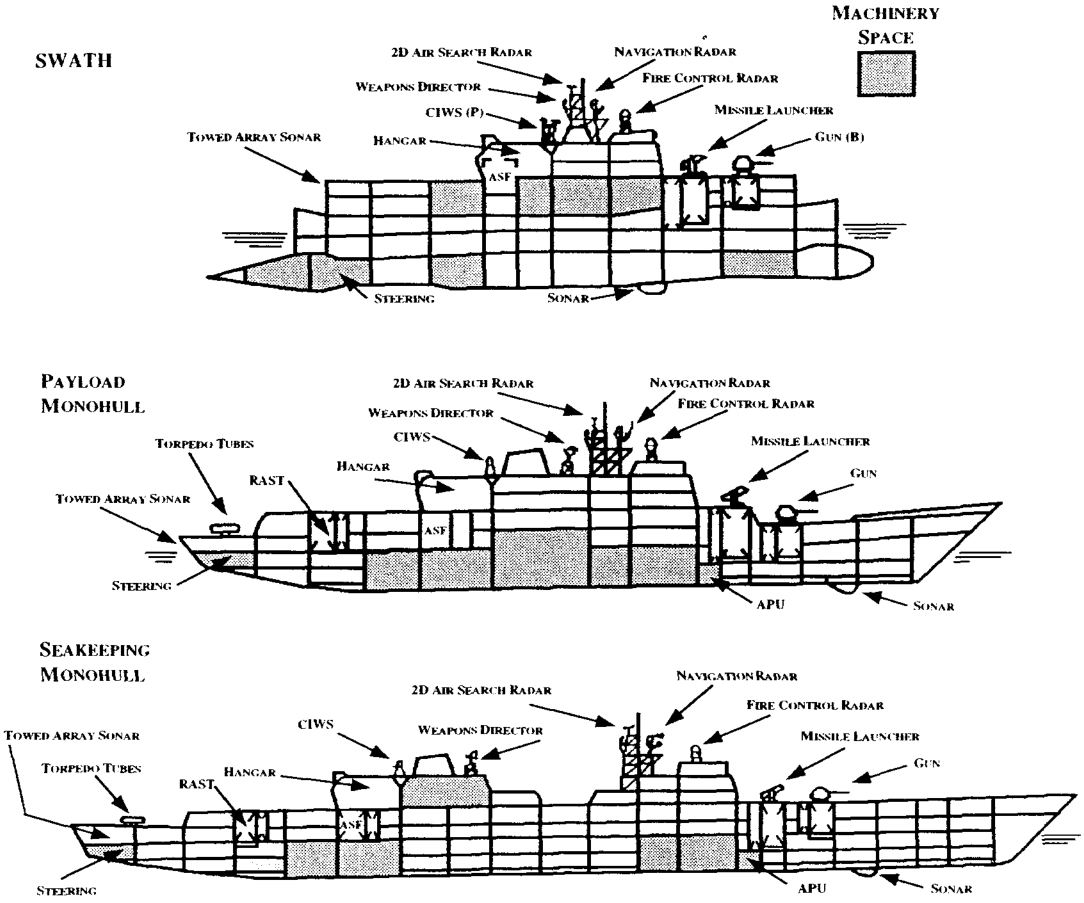

FIG.9 – US NAVY STUDY OF A SWATH COMBATANT AND ITS MONOHULL EQUIVALENTS[25]

A further example is represented by the case of a Trimaran option for a frigate requirement; here the Trimaran hull form is able to provide advantages over the 'equivalent' monohull in terms of maximum speed for the same installed power, improved helicopter performance and greater hangarage and higher antenna – all these attributes requiring considerable increases in ship size for the monohull but are just incremental with a Trimaran.[26] The point here is that the requirement owner would be unlikely to contemplate these options having adopted a 'Requirements Engineering' approach on a nonmaterial 'functional' basis; but with proper Requirement Elucidation such options are encouraged to be investigated and are readily negotiable. Furthermore, this aspect emphasises that there is a strong interaction between the material studies and the requirement derivation, that is to say they are not sequential which is implicit in the Requirement Engineering stance of excluding material studies until the later 'architecture design' phase in the systems engineering cycle.[27] Yet again this points out the danger of neglecting the material issues in a desire to approach the requirements derivation in what is intended to be a non solution manner.

The need for a Comprehensive Architecturally Driven Methodology

From the arguments put forward in this article it follows that the preliminary ship designer should not only be a ready participant in the joint elucidation of the requirement for a sophisticated ship solution, as part of a wider marine based system, whether a naval one or in a transport or servicing commercial role; rather the designer has to bring considerable skills to this exercise and so requires the assistance of a comprehensive methodology and responsive tools, to be a creative partner in the enterprise. It has in consequence been argued by the author[16,28,29,30] that there is a need for a more sophisticated initial sizing approach that brings many of the requirement issues, both operational and enablers/standards, to the fore. The essence of this Design Building Block methodology, summarized in (FIG.10), is that it brings together the current numerical sizing and balancing approach with an architectural description of the preliminary ship design.

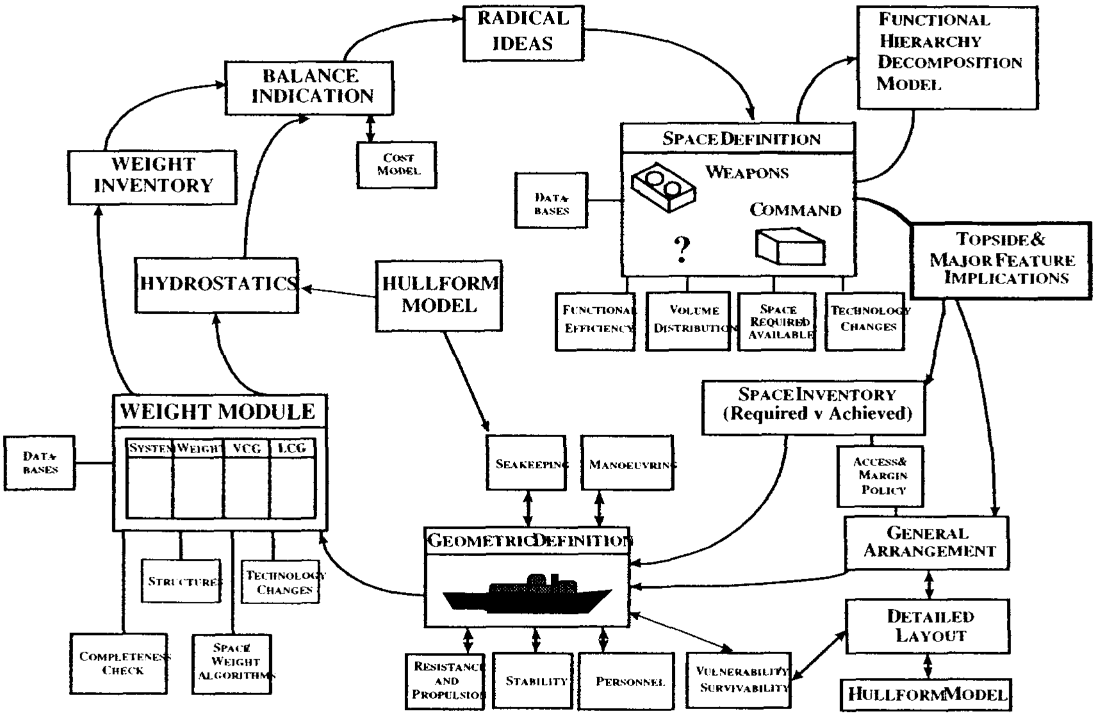

FIG.10 – THE DESIGN BUILDING BLOCK METHODOLOGY[29]

The Design Building Block approach has now been developed as a module (SURFCON) to the Object Oriented preliminary ship design systems (PARAMARINE) produced by Graphics Research Corporation.[31] The approach provides the necessary naval architectural interface to audit the various features of the ship design utilizing the attributes provided by the building blocks, either produced from a library or developed from the evolving three dimensional graphical description. The resultant design description constitutes not just the image shown in (FIG.11) but also the PARAMARINE numerical description of the Master Building Block of the whole ship.

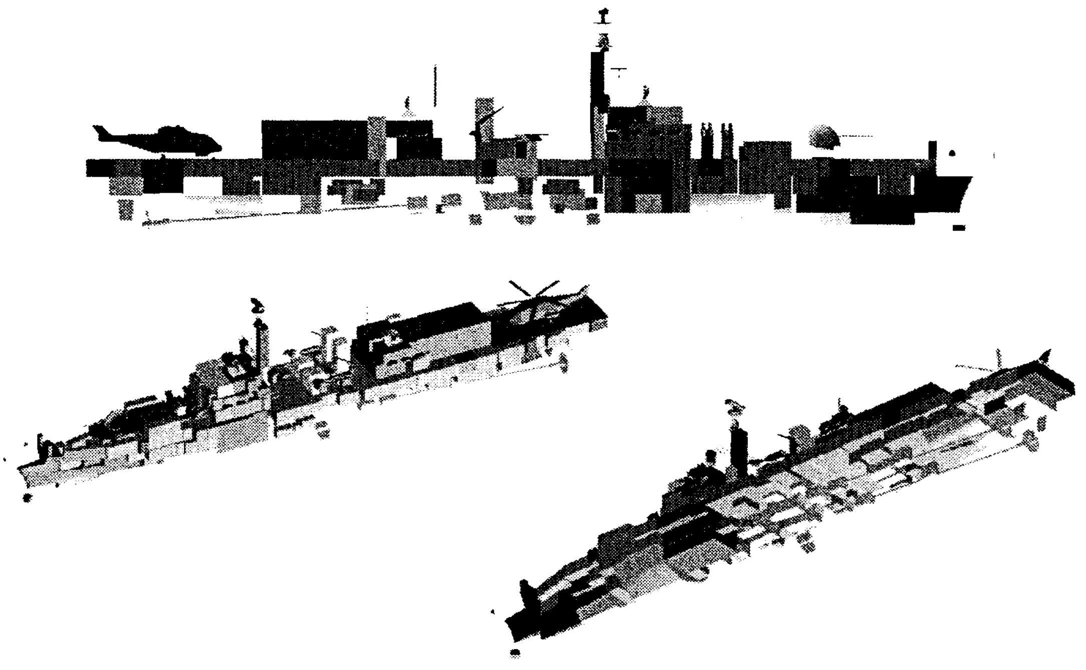

FIG.11 – EXAMPLE OF SURFCON DESCRIPTION OF A FRIGATE CONCEPT STUDY

Together these enable the designer to ensure that a naval architecturally balanced design is produced. Again, in keeping with the philosophy of this article that the ship designer is the professional who provides the appropriate technical input to the concept, this balanced design is not obtained by the SURFCON-PARAMARINE system's use of default 'wired-in' solutions to achieve 'balance', but by the designer in putting together a configuration of Building Blocks. The process entails evolving a configuration by introducing new blocks, refining the blocks to provide a greater number of blocks or moving existing blocks in the current configuration to achieve a 'better' solution and then using the PARAMARINE facilities to check where the consequences of the changed configuration mean the design is no longer naval architecturally balanced. The designer then decides how the design is to be modified to achieve the level of balance that the designer considers necessary, at that point in the design evolution. This process places a heavy responsibility on the designer but ensures that issues are identified, documented and can be faced up to. The process is a necessarily sophisticated and mature approach to what is increasingly recognized as the most vital stage in the design of any complex product.

Not only can the designer thereby reflect many of the users' operational issues in the initial graphical description (which would not be addressable in a purely numerical description) but it is also the case that the Design Building Block approach enables exploration of other major design issues from the commencement of the design. Thus the objectives of such ways of acquisition as Concurrent Engineering (C.E.), both Design for Production and Design for Through Life Support, can rightly be addressed very early in the Concept phase where C.E. requires them so to be.[32] There are other acquisition considerations which modern ships, naval and commercial, are increasingly required to address, often from the commencement of a new concept, for example:

- Standards (military and commercial).
- Safety case regime.
- Risk regime.
- Human factors.

- Adaptability (specifically through life design and placing margins in the right place), which are facilitated by the use of the Design Building Block methodology.

In case it might be thought that the author, in being highly critical of the non material/functional approach to requirement derivation, is antipathetic to a systematic formulization of the operational requirements for a product as complex as a modern combatant, it is pertinent that support for this article's stance has been independently provided by the Professor of Systems Engineering at the Royal Military College of Science, Philip JOHN.[33] In considering the issue of requirements for defence systems, he holds the right approach to be:

- Not to produce requirements without thinking of a material solution and to avoid jumping to one solution.
- Alternative material solutions have to be considered to properly undertake what this article denotes as 'Requirement Elucidation' if the appropriate requirements and constraints are to be found through a clear understanding of the issues.
- All solutions being explored are conditional and an approach of 'so IF that then..' should be adopted.

Thus the conclusion of the current article is that rather than engineering the requirement through an abstract non material approach, the requirement should be arrived at from a joint elucidation by the owner and generator of the requirement together with the preliminary ship designer.

Acknowledgement

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References

1. VAN GRIETHYUSEN W.J. 'Marine Design – Can Systems Engineering Cope?' *IMDC 2000*, Korea, 2000.
2. RABY N. 'Mapping from Capability to Equipment – The Impact on Analysis.' *Defence Capability Analysis Conference*, RMCS Shrivenham, April 2002.
3. HONNOR A.F.; ANDREWS D.J. 'HMS *Invincible* The First of a New Genus of Aircraft Carrying Ships.' *Trans RINA* 1982.
4. CUMMINGHAM T. 'CVF – The UK Future Carrier Project.' *Future Naval Capabilities Conference*, HAS(UK), London, May 2000.
5. PRENTICE K.; ROBB M.; CZERNIEWSKI P.; WADEY S. 'Type 45 and PAAMS – Delivering Capability to the RN.' *3rd Conference on Future Surface Warships*, The Hatton, London, Sept 2002.
6. ERICHSEN S. 'Management of Marine Design.' *Butterworths*, London 1989.
7. WIJNOLST N. 'Design Innovation in Shipping.' *Delft Univ Press*, Netherlands 1995.
8. PRESTON A. Review of 'Modern Warship Design and Development' by N. FRIEDMAN in *Defence*, December 1979.
9. UK MoD. 'The Strategic Defence Review.' *Directorate of Defence Policy*, HMSO. July 1998.
10. BROWN D.K. 'A Century of Naval Construction.' *Conway Maritime Press*, London 1983.
11. UK MoD SMART Procurement Implementation Team. 'The Acquisition Handbook' Edition 1 – April 1999.
12. UK MoD. 'IPT Pilot Guide Edition 4' 19 Jan 1999. *DAWN Public Folders Version*.
13. WOOD J.P. 'Very Grave Suspicion.' *Royal United Services Institute*, London , March1982.
14. ANDREWS D.J. 'Perspectives on the Future Surface Combatant.' *Sea Change 2000*, Jane's Conference, Southampton, May 2000.

15. FINLAYSON R.D.; JOHNSTONE C.C.C. 'Capturing the Requirement in the SMART Acquisition Era – The Future Surface Combatant.' *World Defence Systems, RUSI*, London, November 2002.

16. ANDREWS D.J. 'Creative Ship Design.' *Trans RINA 1981.*

17. PAHL G.; BEITZ W. 'Engineering Design' Edited by WALLACE K. *The Design Council*, London, 1983.

18. BAKER R. 'How to Build a Ship.' Article in Royal Canadian Navy publication as Naval Constructor-in-Chief, 1955.

19. ANDREWS D.J.; BROWN D.K. 'Cheap Warships are not Simple.' Symposium on Ship Costs and Energy. New York, September 1982, *SNAME* 1983.

20. ANDREWS D.J. 'The Management of Warship Design.' *Trans RINA 1993.*

21. ANDREWS D.J. et al. 'SUBCON - A New Approach to Submarine Concept Design.' *Warship 96 Submarines 5, RINA, June 1996.*

22. ANDREWS D.J. 'Preliminary Warship Design.' *Trans RINA 1994.*

23. ANDREWS D.J. 'Future Warship Design and the Prospects for Trimaran Warships.' RINA International Conference R.V. *Triton*: Trimaran Demonstrator Project, Solent Conference Centre Southampton, April 2000.

24. HYDE M.; Andrews D.J. 'CONDES - A Preliminary Design Tool to Aid Customer Decision Making.' *PRADS 92*, Newcastle University, May 1992.

25. KENNELL C.G.; WHITE B.; COMSTOCK E.N. 'Innovative Naval Designs for the North Atlantic Operations.' *Trans SNAME 1985.*

26. ANDREWS D.J.; ZHANG J.W. 'Considerations in the Design of a Trimaran Frigate.' International Symposium, High Speed Vessels. *RINA, November 1995.*

27. BROOK P. 'Systems engineering in the next millennium.' Conference on Systems Engineering for Defence. *RMCS, Shrivenham, February 2000.*

28. ANDREWS D.J. 'An Integrated Approach to Ship Synthesis.' *Trans RINA 1986.*

29. ANDREWS D.J.; DICKS, C A. 'The Building Block Design Methodology Applied to Advanced Naval Ship Design.' *IMDC 97*, Newcastle, June 1997.

30. ANDREWS D.J. 'A Comprehensive Methodology for the Design of Ships (and Other Complex Systems).' *Proceedings of the Royal Society, Series A (1998) 454.* Page 187-211. January 1998.

31. MUNOZ J.A.; FORREST C.J.M. 'Advantages of Software Integration from Initial Design through to Production Design.' *ICCAS 2002*, Malmo, September 2002.

32. Huthwaite B. 'Strategic design: a guide to managing Concurrent Engineering.' *Institute of Competitive Design*, Rochester, MI 1994.

33. JOHN P. 'Acquiring Capability through solution independent requirements – a help or a hinderance?' *Defence Capability Analysis Conference, RMCS Shrivenham*, April 2002.