THE MANAGEMENT OF WARSHIP DESIGN

THE WARSHIP PROJECT MANAGER'S PERSPECTIVE

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ABSTRACT

This article is drawn from the author's experience as a Warship Project Manager (WPM) as well as several tours of duty in surface ship and submarine projects. It considers how the WPM's task differs from that of equipment PMs by discussing the warship procurement process and the WPM's preoccupations. Current and future issues impacting on warship procurement and the pivotal responsibility the WPM has for managing the overall design task are emphasized.

Introduction

This article addresses the issues that are relevant to the management of the process of designing a warship for the Royal Navy from the stance of the Warship Project Manager (the WPM). He is that officer within the Ministry of Defence who is responsible for the management and achievement of the design of a new class of warship. This responsibility is the WPM's central task as the project manager, within the Sea Systems Controllerate of the Procurement Executive, who procures these specific warships.

In the last decade papers and articles have been published on specific UK warship designs, notably on the INVINCIBLE Class carriers[1], the UPHOLDER Class submarines[2] and the DUKE Class frigates[3,4]. Project and design management issues have been covered peripherally although these topics have occasionally been raised in the accompanying discussions. Bryson[3] looked at UK warship procurement as the then Controller of the Navy, but it is largely in the USA that papers have been produced looking at aspects of warship design management and particular procurement strategies from the Navy Department's stance. Several papers considered the outcome of the 1960's McNamara Total Package Procurement initiative applied to US Navy warships[5,6], the reaction to it with the adoption of strategies such as Design to Cost[7,8] and Design Budgeting[9]. Additionally, there has been an ongoing search for a design and procurement methodology, most strongly suggested by a systems engineering approach. This has been modified over the years[10,11,12], and despite criticism[13,14,15] retains the promise of a means to manage the open endedness or 'wickedness'[16] of warship design.

The article commences with the nature of warship design and distinguishes between the WPM and other project managers who are responsible for bringing equipment into service. The procurement steps for warships are compared to other military hardware, together with the tasks and preoccupations of the WPM.

Several current issues affecting the procurement of warships also have profound impact on how the design task can be specified, controlled, assured, assessed and verified. Beyond these current concerns it is already possible to discern a further set of issues or pressures. These will further alter the emphasis in warship design and constrain the WPM's ability to realize the design intent fully.

Nature of Warship Design

'A Warship is engineering's greatest compromise'

The nature of warship design is succinctly caught by Purvis's pithy description above of the warship[17] which may be said to scope the task. There are unique features associated with major warships and these have to be recognized as they govern how the WPM achieves his remit to bring a new class of warship into service.

Before considering the specific stages of warship procurement, it is necessary to place warship design in context. It is common to designate the warship as just another 'platform' delivering a weapon system as does the strike aircraft or the tank. This is a false parallel in two major regards:

- The term 'platform' implies a militarily passive delivery system as an adjunct to the weapon system. The warship does not exist because of a single weapon system, rather it incorporates an integrated combat system but only as part of its total function. Furthermore, the combat system has a multi-warfare capability solely because of its cohesion on the warship.

- The warship is not simply the sharp end of a wider combat system providing that element of the full combat system for a very short mission time. The warship is closer to being a total military entity with its own delivery systems (e.g. helicopters) and an infrastructure providing extended power, mobility and personnel and material support, within an environmentally protected shelter.

In scale, the largest RN ship has over one thousand compartments and supports 1300 personnel whilst the US Navy carriers are awesome in size; even the smallest fighting ship has 70 compartments. Scale is also relevant to mission duration; ships do get replenished on mission but quite differently to combat aircraft which after a few hours return to base where separate personnel from the operator(s) take over to restore the platform to its mission effective state.

It is not just a question of scale, the warship has a vast range and diversity of functions and technologies. This leads to the fundamental nature of the warship design task best characterized by the term integration. This functional diversity can be seen from the studies on reducing the manpower onboard a frigate. The recently proposed YARD 50 man frigate (FIG. 1)[18] and less well known Canadian Study[19] highlight the difficulty of excluding many of the secondary warship roles arising from the presence and permanence on station of the total infrastructure provided by a major warship. Typical tasks are boat handling, showing the flag, search and rescue, disaster relief at sea and ashore, not to mention multi combat missions requiring the full range of communications, radars, sonar, electronic warfare, self-defence and command & control. Having to do all this means that departing from conventional hull forms and adopting advanced naval vehicle (ANV) solutions rarely occurs for major warships. Although ANVs have spectacular performance in certain regards[20] and often appear cost-effective, particularly because of their small crews, they lack the multi-mission flexibility of the conventional hull. Producing a functional specification for a multi-mission warship is difficult. Much of the utility it

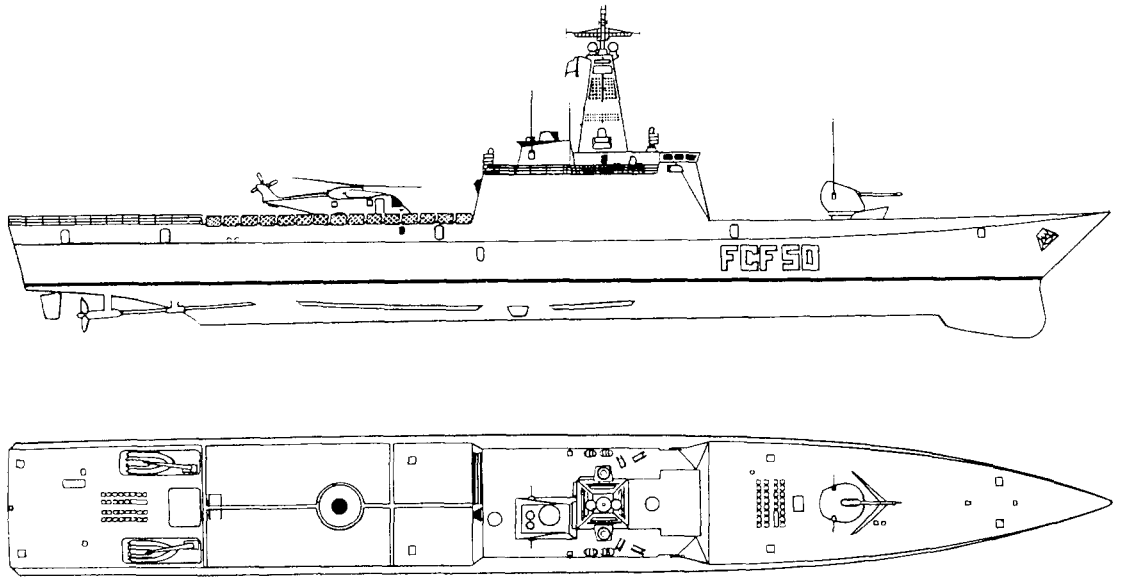

FIG. 1—YARD'S 1990 50-MAN FRIGATE

exhibits arises from its very presence and since most of the ship features are of a relatively low level of technology and individually cheap and interdependent, providing one of these capabilities often leads to incorporating others.

Secondly, the technology is diverse. The most technically sophisticated and costly components of the warship are in the combat system. Its expense essentially lies in developing the electronics and, increasingly, the production of the software that goes with it. For the ship systems, whilst the computer pervades the design, technology ranges right across the engineering spectrum from the construction and assembly tasks to bought in and specially tailored electronic control systems.

This diversity explains in part the warship design task and why its integrative nature is so complex. There are tools and guidelines to assist the WPM, his team and his contractor. Often they are *ad hoc* since every ship design is different and to try to mould them all to the same process is to court disaster. Nevertheless, the integrative task needs to be managed and the most important control mechanism is the ship design itself. The multifunctional ship[21] has to provide a flexible response in very hostile environments. So it is essential to define the overall physical parameters long before the details or even the viability of the design is discernable. This is quite different from what is normally meant by synthesis and from most mechanical and engineering design. It contrasts starkly with the design of electronic systems which are conceived as hierarchies of functional blocks with their interfacing realized through computer code.

The only solution to the ship design problem is to break into the design and then (to use Rydill's analogy[22]) 'having got your onion, peal off the layers'. As the design is refined, both in detailing the component systems and with the increasing overall definition, there is continual retesting to greater levels of precision on the overall features. Here the shorthand of S^5 (speed, seakeeping, strength, stability and style)[23] serves as a useful summary of at least the naval architectural issues. So where does integration fit into this? Precisely through the physical and functional definition of the total ship conceived in the initial synthesis[16]. The subsequent fragmentation to achieve component system design and validation through the overall naval architectural features (S^5) is glued together through the vital tool of the spatial and mass balance. Thus the production and maintenance of the General Arrangement can be said to provide the ultimate in top down management control.

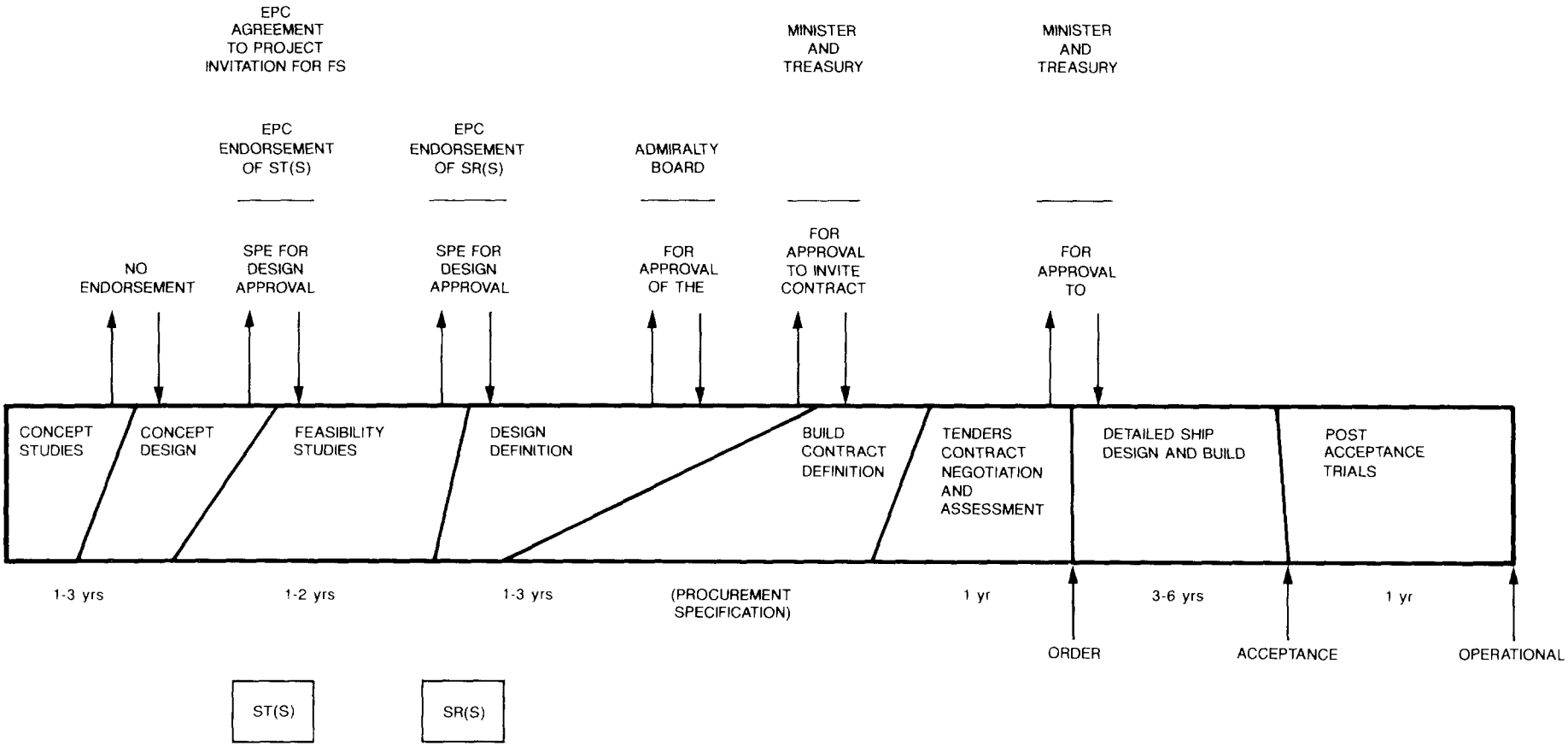

FIG. 2—UK WARSHIP DESIGN PROCESS

The Stages of Warship Design

The stages of the Warship Design Process both constrain the WPM and provide him with clear milestones. The stages are derived from the rather outmoded MOD guidelines[24] which were never truly applicable to the total warship because of two fundamental features, one at each end of the design process:

(*a*) A new warship design does not necessarily originate from clear threat assessments as would be the case with a new weapon system, and even its associated platform. Instead, a warship concept normally arises from the need to replace an existing ship class. This may be a necessary updating in the general level of technology, however more likely is the need to get to sea a major new weapon or sensor system, e.g. Towed Array for Type 23 Frigate or the Sea Dart System for Type 42 Destroyer. So at concept, whilst the Defence Staff perceive a conglomeration of all the desired military and maritime features, this is countered by the pressure to keep down cost, especially Unit Production Cost (UPC)[23]. In the resultant dialogue between the concept team and the Defence Staff, the former provides an informed guide on the likely solution integrating all the disparate elements, both those contributing directly to the combat system and those doing so indirectly as ship systems. These latter may directly support the combat system, the personnel (many of whom are strictly part of the combat system), or the float and move elements which themselves also have significant and vital military features (such as signature suppression or survivability).

(*b*) For a major weapon equipment, the decision to enter production of a series of identical units is taken after several prototypes have been produced and have then demonstrated that the Staff Requirement has been met. This is not possible with the warship because of the scale of the integration task and the cost of the ship relative to the limited number of units in a class. It is sometimes argued that the first of class (FOC) is the prototype; however, a true prototype exists to demonstrate the solution to the requirement before the production run commences. To introduce a major new weapon system (or often several, as in the case of Type 23[4]) concurrently with the first of class means that the major weapon system is being developed alongside the ship design. So the detailed design of the ship, providing the final definition for physical construction, is undertaken during the construction phase.

The following paragraphs outline specific stages of the warship procurement process shown in FIG. 2 and puts the subsequent discussion in context. Other essential activities take place in the procurement process, but the ship design process has been emphasized, since:

(*a*) the level of design undertaken at each phase is governed by the design definition required at the phase's end point and is the minimum necessary to inform or provide for the next step in the process at acceptable risk;

(*b*) the term design is often taken to refer to the final stage of the technical evolution, i.e. the engineering drawing phase when sufficient definition is realized to enable manufacture. In this regard, the WPM, as the contractual customer for warships does not undertake full ship design. However, this is somewhat pedantic since creating a concept is the first stage in any design evolution and specifying the design to be realized largely determines the material solution. Thus all steps in the design process are informed by preceding steps and there is a design continuum.

Concept Studies

Concept studies commence in most cases ahead of a clear requirement. One should not be surprised by this for to use Rowland Baker's adage[25], 'as the chicken comes before the egg, so does the warship before the staff requirement'. Wide-ranging concept studies are closely linked to the prospective concept for weapons (including sensors) and major ship systems (e.g. propulsion or hull configuration) as well as to initial thoughts on the operational concepts. Commenced sufficiently early, these studies can identify where research resources should be devoted. The worth of the studies is dependent on the design tools and data but even more the preparedness and skill of the concept team to make some pretty brave judgements.

Concept Design

The new warship concept becomes clearer as the timeframe becomes more focused some 10 years before FOC In Service Date, and the approval process for Staff Target, Staff Requirement and ordering the FOC. Concept work must still be divergent in the range of solutions to be considered, i.e. new build, conventional monohull, ANV, conversion of ship taken up from trade (STUFT) or even a substantial ship life extension programme (SLEP) of an existing naval vessel. But more important than the range of material solutions is the production of a Baseline Concept Design sufficiently defined to be costed with some accuracy. This then provides the basis for investigating incremental capability enhancements. FIGS. 3 and 4 illustrate typical examples of payload and ship characteristic exploration on an ASW Frigate Study from Ref. 26. This is the major concept process as it provides a whole ship basis for an informed dialogue with the Defence Staff on what is affordable in evolving the requirement. It is complemented by Operational Research studies, either on the whole ship characteristics or aspects related to major weapon system choices. From this dialogue the staff produce the Staff Target (ST). The concept group is closely involved in its production and provides the joint authorship with the Staff of the Supporting Paper to the Equipment Procurement Committee (EPC)*. The object of the paper, aside from justifying the proposed Staff Target, is to seek the EPC's agreement to commencing feasibility.

Feasibility Studies

These substantial studies are managed by a fully fledged Project Team established under a Warship Project Manager (WPM). They provide the technical justification for the submission to EPC of the more substantial Staff Requirement (SR). For a major warship, these studies may be placed in industry either via one or more support contracts or as a competitive exercise where two or more parallel design contracts are undertaken. In the former case, the direction of the exercise is under the WPM's control as essentially a MOD-managed study using commercial resources in lieu of an in-house design team. For the latter, the competing contractors have to produce their own designs, albeit from substantial discussions with MOD specialists, and then these proposals are subsequently assessed by the MOD Project. Because the designs may take some 12 months and require typically 30 man years effort for each entry, such competitive exercises are expensive.

This stage explores the viability of the requirement and provides a clear and costed justification for the Staff Requirement. Since the outcome may well modify the requirements, parallel competitive studies may not be an efficient use of limited resources. Whichever approach is adopted, the WPM still has to manage several significant activities, e.g. a tendering process, a presentation to

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* Since April 1992 this committee has been known as the Equipment Approval Committee.

Industry, an Invitation to Tender (ITT), and the assessment and clarification of tenders. At the end of the Feasibility Studies he receives an output of typically 20 volumes from each competitor and then has to manage their assessment by

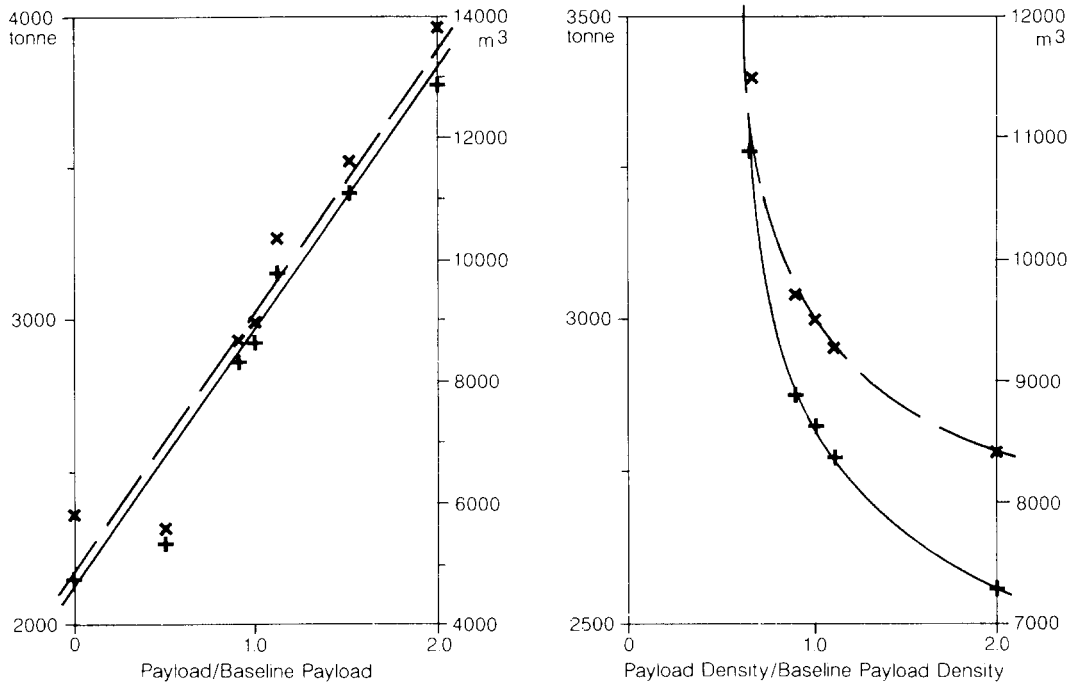

FIG. 3—TYPICAL PAYLOAD EXPLORATIONS AT CONCEPT DESIGN. DISPLACEMENT (×) AND VOLUME (+) FOR (*a*) VARYING PAYLOAD WEIGHT (LEFT) AND (*b*) VARYING PAYLOAD DENSITY (W_p CONSTANT) (RIGHT)

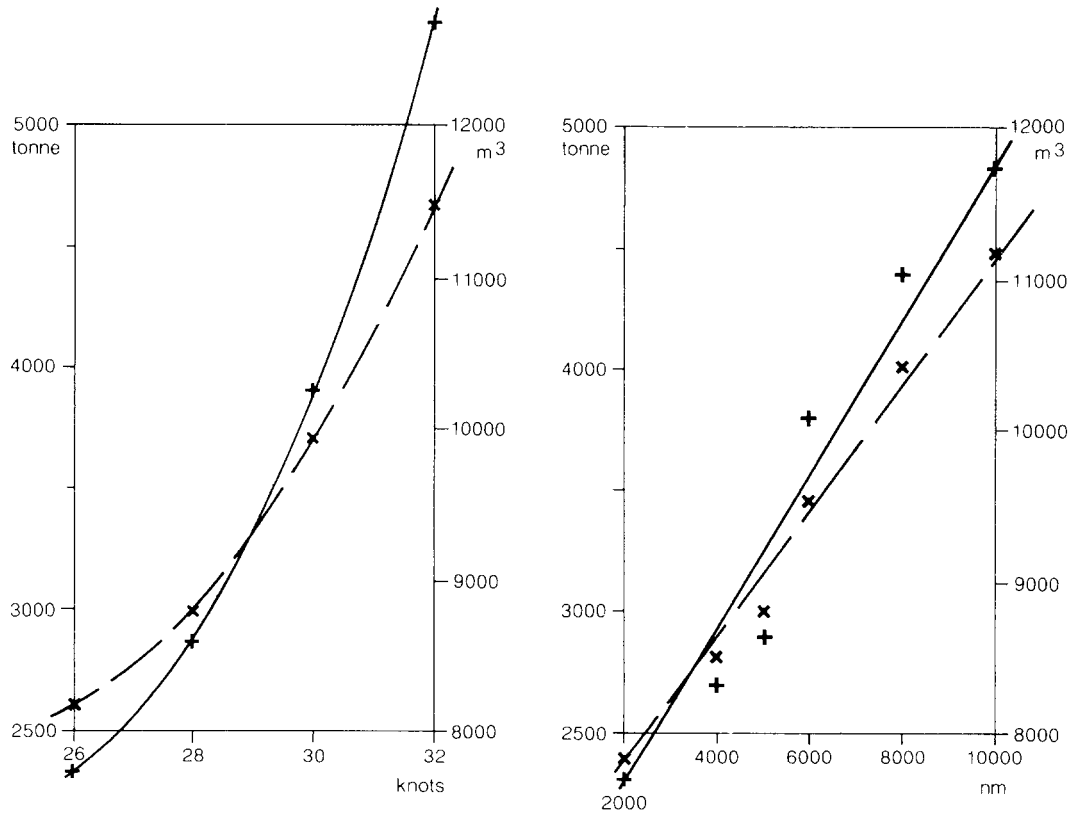

FIG. 4—TYPICAL SHIP CHARACTERISTIC EXPLORATIONS AT CONCEPT DESIGN. DISPLACEMENT (×) AND VOLUME (+) FOR (*a*) VARYING MAX. SPEED (LEFT) AND (*b*) VARYING RANGE AT 18 KNOTS (RIGHT)

up to 100 authorities. So 12 months' feasibility can require a further 12 months to assess, which is followed by steering the Staff Requirement through its various formal levels to the EPC and then beyond to Ministers to authorize expenditure for the next step.

Project, Design or Ship Definition

Retention of more than one option beyond feasibility is to be strenuously avoided since inadequate definition at this stage will mean too superficial a statement of the technical requirement. The resultant procurement specification will be in considerably more depth and less tentative than the feasibility study report. Thus, whilst feasibility will have a General Arrangement for each option and probably some 10 critical drawings for the preferred option, the procurement specification will have typically some 200 drawings providing in-depth guidance not just on the General Arrangement, but such features such as the overall structural configuration, tankage arrangements, upper deck configuration, major compartment arrangements and system schematics. This should be compared with the final 3000 working drawings produced for a typical frigate and ten times that for a nuclear submarine or an aircraft carrier.

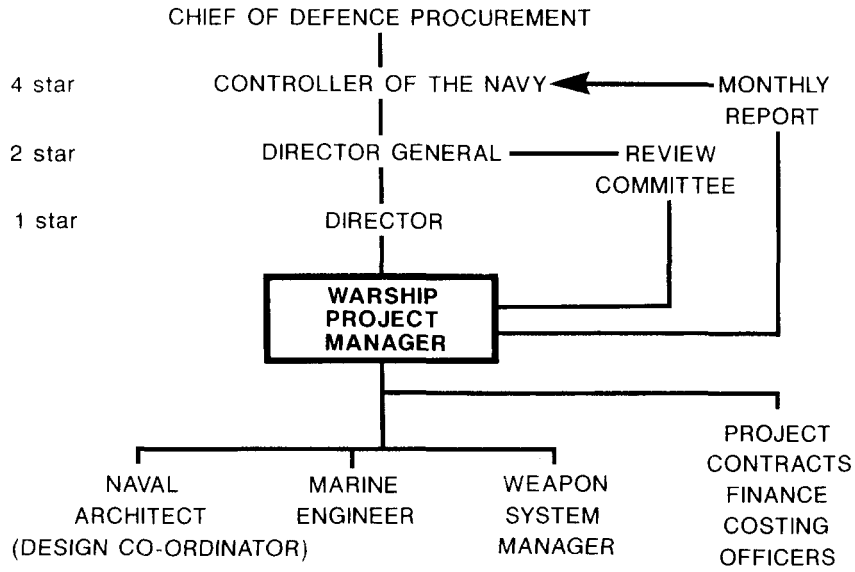

FIG. 5—THE WPM'S PLACE IN THE PROCUREMENT HIERARCHY

The Tasks of the Warship Project Manager

Within the MOD, managment of the total design throughout the procurement process lies with the WPM. He does so as the leader of a multi-disciplinary team of engineers responsible for the hull and ship integration, the machinery, the combat system, the support, production and cost aspects, and of non-engineers for the contractual details and financial provision (FIG. 5).

The WPM's tasks can be spelt out formally in Terms of Reference. However, these do not convey the essence of the responsibilities and preoccupations of a WPM. It is contended that he has five overriding concerns:

- survival of the project
- achieving approvals
- producing and maintaining the contract
- preserving the programme, both schedule and money
- sustaining the project team.

The author has no doubt from his recent experience on at least two major warship projects for which he was the WPM, that his was the ultimate responsibility for his project's survival. The WPM is a relatively lowly manager in a vast procurement bureaucracy with four pople between him and the Chief of Defence Procurement (FIG. 5)* so his power to ensure survival is limited. The WPM is only there because of his project and he and his team only continue to perform as the focus for that programme. So the WPM is motivated to defend and preserve his project and the resources necessary to sustain it. This means the WPM, whilst being thought of as the manager of his team by the organization above him, is also concerned with looking upwards to ensure his project is not under threat. If it is to survive he has to marshal the arguments so that should the programme be cut in size, stalled or the budget squeezed, then it is done in a reasonably coherent manner that preserves the capability of the project and subsequently his prime contractor or contractors to deliver the best product within the constraints. To ensure this, the WPM has to take every opportunity to provide an up-to-date picture of the project's status and to focus briefings on the particular recipient.

The early stages of a new warship project are dominated by the treadmill of approval, noticeably by the EPC of the Staff Target and the Staff Requirement. These take a minimum of four months and can take considerably longer due to the approval process requiring progressive circulation and agreement throughout the MOD at each level shown in FIG. 5 before reaching the EPC. It can seem like a game of snakes and ladders where the snakes far outnumber the ladders. The team of the Defence Staff and the warship project have to revise the Target or Requirement continually, with more and more features being insisted upon by specialist lobbies which to the project seem only to have concern for their element of the expanding total. The team also has to amend the Supporting Paper, re-justifying the submission in response the changes in emphasis and challenging arguments so that the paper takes on the appearance of a leaking sieve. Despite often questioning this process, it is appreciated that the sums of money are vast and there is a natural reluctance by governments to pay what can be seen as an excessive insurance premium.

With the requirement endorsement and subsequent Ministerial and Treasury approvals, money can be spent, provided it has been bid for and maintained through the annual expenditure process. Given approvals, contracts can be placed. These may provide the WPM with resources to achieve particular tasks assisting Feasibility or Design Definition or provide the agreement with the Prime Contractor to produce the warship itself. Either way, the product, be it design data or the ship itself, is governed by the contract which ultimately means the ship is only as good as the specification called up in the contract.

Although Naval Engineering Standards underpin the warship specification, many specifications will be out of date, about to be revised, just not applicable to the particular ship or inconsistent with the specific procurement approach adopted. Thus each warship project has to produce its own specification. Current projects do not have large teams[27] and cannot have all the expertise across all the engineering disciplines. If the ship is a specialist ship, like an LPD, which has not been designed for 30 years, then the project will not have expertise on that specific ship type. FIG. 6 turns the man-in-the-middle image (FIG. 1 of Ref 3) inside out, with the project as the tip of the iceberg of those in the MOD that are involved in producing the specification. The project team has the ultimate responsibiity to manage, write, revise, edit, seek agreement and produce the specification, but only after receiving and resolving contributions,

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* The recent changes in the Sea Systems Controllerate (SSC) have eliminated the 3 star Chief Executive so there are only three levels between the WPM and CDP.

positive and negative, from over 100 different authorities. Finally, the specification has to match the aspirations of the Staff Requirement and the constraints of the budget and the procurement policy, so it will never be watertight.

Projects are often judged solely by whether they have come in on time and money. Whilst cost can be elusive both to define[23], and to identify at the end of a ship build[28], whether a ship is built to time or not is obvious to all and beyond debate. Once the ship has been ordered, there is usually public visibility of any build delay. Prior to this however, either for expenditure restriction reasons or the inability to achieve the necessary firm approvals on time, the WPM's programme too often moves to the right.

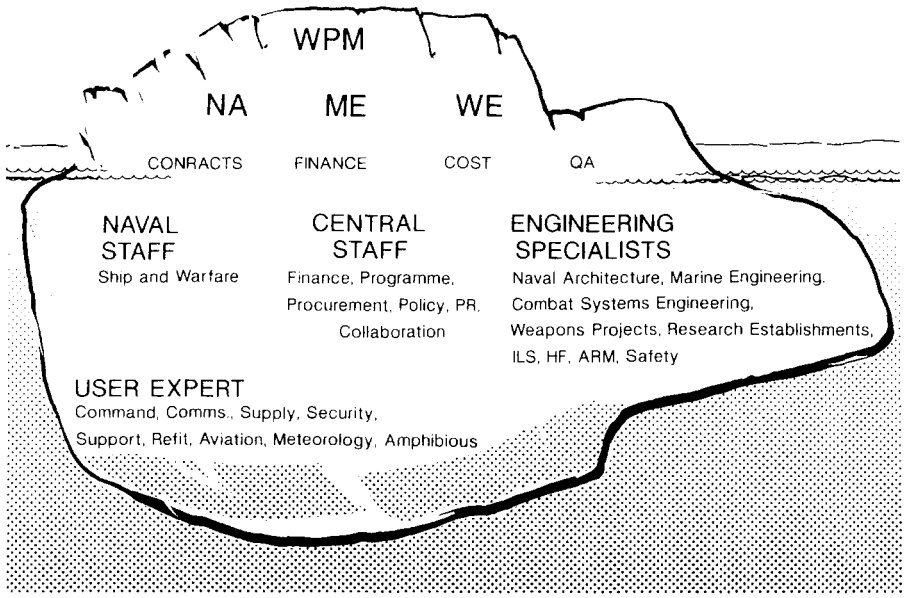

FIG. 6—THE PROJECT AS THE TIP OF THE MOD ICEBERG

Organizational issues outside the project team can markedly affect the manner in which certain project activities are accomplished. Organizational change is a continual preoccupation within the MOD and can undermine the cohesion of the project team. It is rare for a project manager to chose his team, and often he just inherits a project from a predecessor. Despite exhortations to the contrary, the WPM and his senior professional staff are unlikely to serve more than three or four years in post, unlike industry where project mangers see their projects through to completion. This is partly explained by the much longer in-house timescale from commencement of feasibility, through to acceptance of the first of class. However, it is also due to the Civil Service and naval career patterns which require continual rotation so everyone experiences the widest possible range of jobs to facilitate subsequent promotion. Thus, the WPM has to cope with constant re-learning in the team, provision of replacements on time and scrutiny of candidates by his senior staff. Despite this, a project team builds up an *esprit de corps*, since a new warship project is seen as a dynamic group with a clear task and a specific end product.

The Characteristics of Warship Project Management

The characteristics of the design and the project management function change as the project progresses so it is debatable whether there are any universal, or even national characteristics, in the practice of Warship Project Management. The WPM's early preoccupations with approvals are quite different to those downstream. Once the ship is under construction, the major interface becomes that with the shipbuilder. Despite this watershed, there are

clear patterns that apply throughout the procurement process and, whilst the construction process is dominated by the ship build programme, major design issues remain.

Early in the build, design aspects related to interpretation of the specification can hold up the shipbuilder's detailed design work. The project team then has to seek clarification or modifications from the relevant engineering specialist or user authority and resolve conflicts within the project team itself. Later in construction, the progressive acceptance of compartments and systems means that questions of interpretation are posed to the project and the specialists, providing a strong strand of design-related continuity. Often there are modifications not achievable on the FOC, or changes in requirement that can only be incorporated into the design and within the programme constraints of the follow-on ships. So, the evolving design provides the focus and a constant managerial theme for the WPM in gauging the project's progress.

Sub-Structuring the Ship Design

This essentially integrative task is managed through sub-structuring the multifunctional problem and, complementarily, ensuring an overview through control of the General Arrangement. The sub-structuring is most readily seen from the Work Breakdown Structure (WBS) (FIGS. 7 & 8). Level One indicates the main areas of responsibility allocated to senior team members in producing the specification, overseeing the design and construction issues and managing the acceptance process. Thus, the ship's structure is broken down on a physical and configurational basis, whilst the ship systems and the combat system are divided functionally down to the sub-systems before they too relate to physical components and their configurational relationships.

Certain aspects which do not fit this broad pattern under the Total Warship Management task are the direct Project Management functions, the General Design aspects and the Support aspects. General Design covers a somewhat mixed bag with environmental and signature concerns contrasted with a series of overall ship features, the arrangement concerns and aids to design, including integration. Placing integration under such a sub-structuring pattern demonstrates the limits of such an approach, since it is hardly a sub-system separable from the overall layout, weight control and the design management task. Despite this, the WBS hierarchy provides the WPM with the basis for parcelling out the detailed management of the design amongst his principal deputies. Thus the naval architect takes on the hull, structure and ship systems, the marine engineer the propulsion, auxiliary and power systems, and the combat system engineer the weapons and command, control and communications (C^3) systems.

Whilst apportionment of most systems is along obvious engineering lines, layout, general design co-ordination and integration are placed with the naval architect alongside his responsibilities for the hull aspects, so he is variously designated the Design, Ship Design, or Design Co-ordination Manager. This role of the naval architect as the *primus inter pares* is increasingly questioned, despite the fact that naval architects maintain that ship design is the *raison d'être* for naval architecture[29]. One reason for this questioning is that the true *warship* project now includes responsibility for the combat system design and not just the physical integration of weapon equipments. In the preliminary stages of warship design, the lead role of the naval architect is still accepted, given the naval architect's sole ability to size the overall ship and determine its form since this is largely governed by concerns of displacement, gross volume, and S^5. Furthermore, when the 'general design issues' in FIG. 8 are considered, the vast majority of the so-called constructional constraints, environmental aspects, design aids and of course arrangement management, lie with the ship

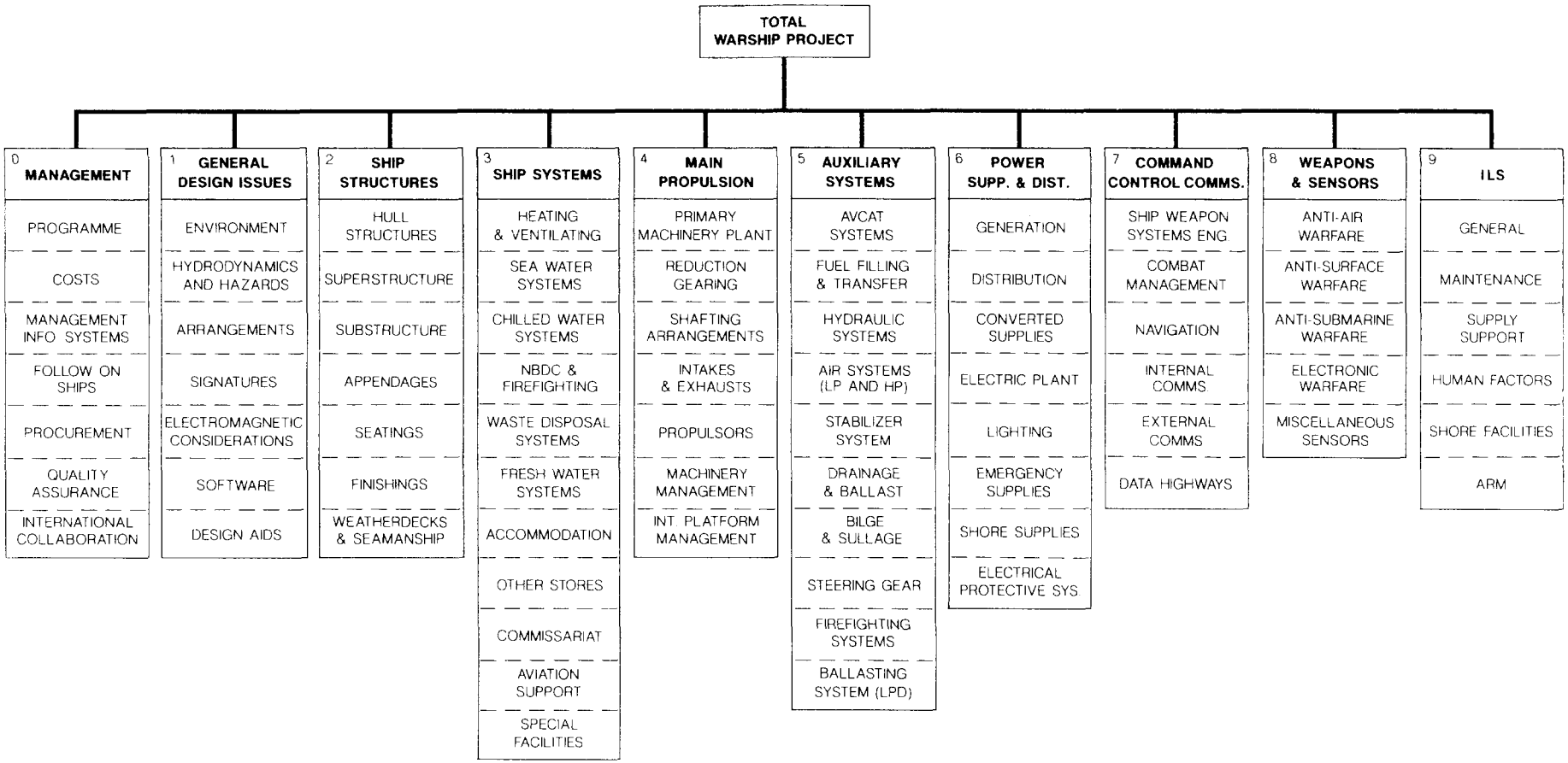

FIG. 7—TYPICAL WORK BREAKDOWN STRUCTURE FOR A WARSHIP (LEVELS 1 & 2)

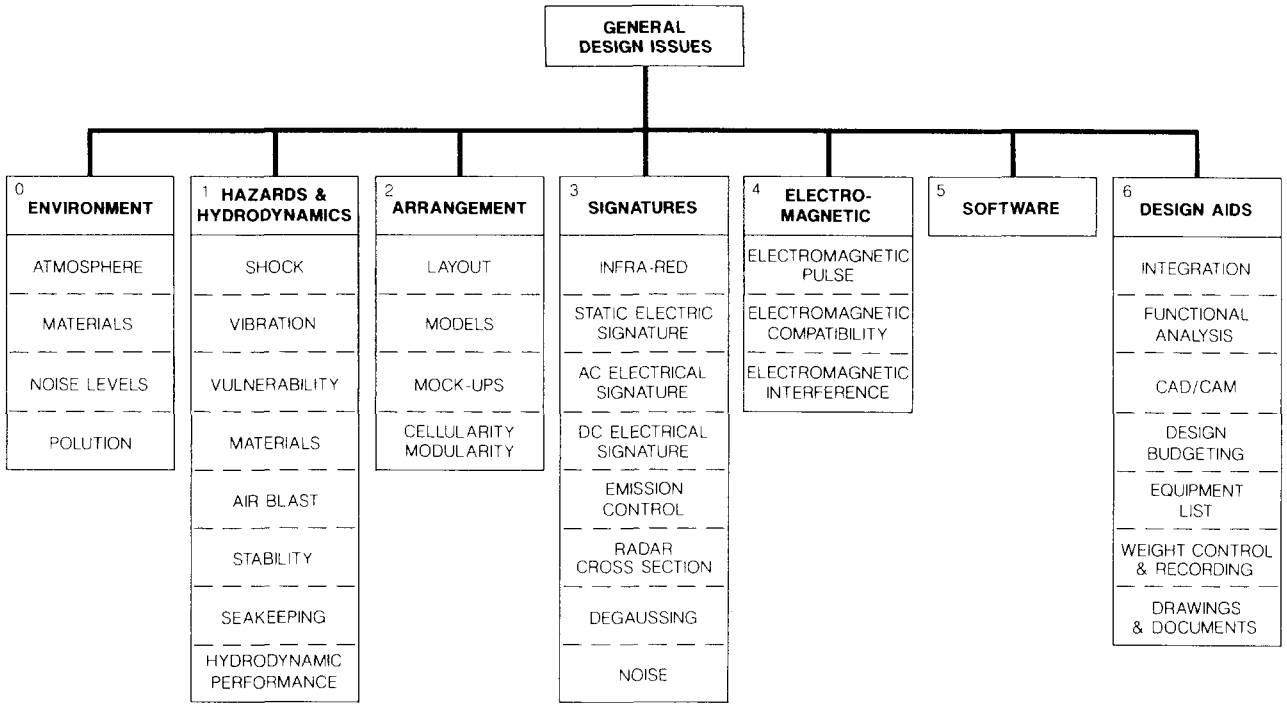

FIG. 8—TYPICAL WORK BREAKDOWN STRUCTURE FOR A WARSHIP (LEVELS 2 & 3)

designer. The key to design integration is the General Arrangement which remains the naval architect's responsibility given his need to keep control of the weight and location of everything. Thus for the naval architect everybody else's problems invariably become his in compromising stability, structure, seakeeping, speed or style (the latter primarily through layout conflicts). Whether current initiatives in design management will change this situation is explored in the penultimate part of this article.

External Mechanisms of Controlling the Project

Thus far, the impression conveyed is that the only checks and balances on the WPM arise from the major approval process of EPC endorsement of ST(S) and SR(S), followed by Ministerial and Treasury approval for major steps in expenditure. However, there is also the annual public expenditure round looking at the ten year forecast and involving the Defence Staff, as the naval customer, and the Office of Management and Budget (OMB). Additionally, there are the regular external audits by the National Audit Office and the House of Commons Defence Committee. This latter august body can and does call for evidence on the performance of particular projects and has been known to grill WPMs on the design and project management of their ships[30].

Aside from these essentially external checks, there is the normal reporting structure in the SSC indicated by FIG. 5. The six-monthly First of Class Review Committee has representation from the Defence Operational Staff, Naval Fleet Support, the Senior Professional Engineers (SPE), contracts and finance areas and undertakes an in-depth scrutiny of the project. Additionally, the SPEs act as Controller's experts in their respective disciplines of naval architecture, marine engineering and combat system engineering scrutinizing the technical aspects of the whole warship design. They do so at every significant step in the procurement process both on the current level of design disclosure and on the specification to be used to obtain contractor responses in the subsequent phase. This may sound a daunting task, but essentially the SPEs head up the specialist engineering organizations that the WPM has been using as his main sources of specialist advice to assist in producing the specification or scrutinizing the design or tender response.

Other Warship Project Management Approaches

It might quite fairly be asked whether the structure adopted in the SSC for the management of warship design and procurement is necessarily the most effective. It is certainly the case that the Controllerate has been under an almost continual state of reorganization since the old DNC, E-in-C and DEE were combined into Ship Department alongside a Naval Weapons Department. Continual reorganization does not seem to be a uniquely British affliction[31,32] and given the imminence of further reorganizations there seem little point in reviewing the various historical changes as they largely involve the top down restructuring and so have not fundamentally affected the Warship Project.

The major exception to this was the incorporation in 1986 of combat system engineering into the warship project. Thus the purely hull, mechanical and electrical orientated *ship* project became a truly whole ship or *warship* project with the addition of the Weapon System Manager to the WPM's team. Whilst the naval architect has always been concerned with integrating the weapons into the ship, the pre-1986 ship project's responsibility was limited to the physical interfacing of discrete weapons equipments on the ship. Now the full warship design and procurement project is organized as a team of three or four groups or sections with typically 10 people in each. With fewer staff in a given project,

contractors are increasingly used for direct project support. Such design consultancies enable the WPM to discharge what is becoming an ever more demanding task with less directly employed staff. Why the task is growing is explained in the remaining parts of this article. However, before this is considered, there follow three examples of how similar national organizations approach the in-house warship design and procurement task.

The US Naval Warship Procurement Approach

The US Navy's equivalents of the WPM, for major warship projects such as DDG 51 (BURKE Class) and SSN 21 (*SeaWolf*), are at a higher level than even the Director level WPM adopted for the early stages of the Type 23 and for UK new construction submarines (TRIDENT, Type 2400 and SSN 20). They are often line naval officers rather than the Engineering Duty Officers trained in ship design similarly to the British Constructors[33]. However, whilst these Ship Acquisition Project Managers (SHAPMs) do often acquire engineering expertise in their teams, they do not exercise the equivalent of the UK WPMs' Design Authority. In the USN, the Naval Sea Systems Command (NAVSEA) Ship Design Director (SEA 05)[32] has the technical responsibility and a very large part of the major design work is undertaken in-house under his specialist 'codes' corresponding to the SSC's Senior Professional Engineers organizations. Thus the architectural definition of space, configuration, weight and stability is managed for all new warship designs in the hull specialist code group. This ensures continuity of practice and layout philosophy, together with a high degee of audit and management necessary with a very diffuse and large design team. The SHAPM thus operates in a matrix management arrangement more akin to major construction projects in the Offshore Industry, in contrast to the UK philosophy of defence procurement project management.

The French Naval Warship Procurement Approach

What distinguishes French warship procurement from both the UK and the US approaches is that the whole process for the ship and a large part of its equipment is under the direct management of the procuring organization. Thus the Director of Naval Construction (DCN), responsible through Délegué Générale de l'Armament to the Minister of Defence, has both the equivalent of the WPM (Programme Director or DP) and the Prime Contractor (the DCN dockyard) under his direct management authority. Aside from the fact that the DCN dockyard only assumes responsibility for design integration at the detailed pre-construction phase, the Prime Contractor analogy also falls down with regard to the propulsion and combat systems where separate divisions of the DCN retain procurement responsibilities, including manufacture, to the Programme Director.

Additionally, the DP has a 'contract' within DCN with the Head of STCAN (the technical bureau). STCAN provides a small co-ordinating Project Team of a naval architect and a 'combat architect' who co-ordinate the involvement of the specialists in STCAN throughout the design. This is akin to the USN NAVSEA arrangement with design work performed by specialists and, crucially, one specialist is the naval architect performing the weight, space and stability alongside maintenance of the general arrangement. This fragmentation of the co-ordination responsibility leaves the DP relying on his quasi-contract with STCAN's project team for the viability of the warship design. However, he is given the money to employ the project team and the STCAN experts on his project for those tasks unique to his project. Design Authority seems less of a concern because in the French system all the principal design participants, right through to acceptance, work directly for the DCN.

A Specific Royal Australian Navy Warship Procurement

Within Australian Defence Procurement the procurement of the COLLINS Class SSKs is a very major procurement task[34]. From the beginning, it was recognized that the design and construction expertise would have to be provided from abroad, although maximizing Australian industry's involvement was a political imperative. In stark contrast to the French, a prime contractor was established—the Australian Submarine Corporation (ASC) with approximately 50:50 holdings by Kockums, who won the PD competition, and by an Australian consortium. It is not appropriate to discuss the project in detail, but it is pertinent to point out that the project's success, thus far, seems due to:

(*a*) The seniority and continuity of the Project Director. Rear Admiral Hughes is a naval engineer with direct access to the Navy Office and the (MOD) Procurement Secretary and has been in post since 1983.

(*b*) The project team is sufficient (120 people) to exercise detailed involvement and visibility as the informed customer who focuses on risk management.

(*c*) The considerable investment (25%) on through-life management and data system.

(*d*) The considerable investment (A$15M) in the project team's own management system.

Current Issues in Warship Design Management

It was pointed out a decade ago[23] that the pressures on the warship designer had changed from producing the best ship, to the most cost-effective, to now the best that could be provided for the money. Often, that latter imperative is taken to mean minimizing UPC. This is completely counter to the cost-effective approach which looks to minimizing whole-life, not just initial procurement, cost. The pressures on defence budgets even before the breakup of the Warsaw Pact and the subsequent political demand for the 'peace dividend' mean the ship designer is being exhorted to reduce cost. Conversely there is the far less clear international picture where the 1991 Gulf War demonstrated that greater international instability means the military threats which new projects are intended to counter are, if anything, more diffuse. There used to be one clear potential adversary and the UK maritime contribution to countering him was relatively clear cut[35]. Now any new warship is expected to do more for even less. This is the overriding defence procurement issue such that other issues are a means to that end and have to exist and survive within this environment. The issues identified earlier as the preoccupations of the WPM, those of survival of his project, getting approvals, preserving programme schedule and money and keeping his team together are likely to be intensified.

Such current issues are considered below under the headings 'The Search for Assurance' and 'New Initiatives'.

The Search for Assurance

With this dominant political constraint there is an increased emphasis in warship project scrutiny with assurances being sought right across the design on what are essentially engineering issues.

Availability, Reliability and Maintainability (ARM)

These related aspects have had prominence in equipment design for many years. Extension of ARM to the total ship is the next step. Because of the disparate nature of the various systems in the warship and their interdependence this is not straightforward. Individual weapon systems are specified with

demanding and precise ARM targets. These relate to specific threat scenarios and clear performance requirements. This approach can be extended to the complete combat system relatively easily. However, full assessment of system reliability then breaks down, since individual weapon equipments are dependent on ship services (e.g. air conditioning and chilled water) for continued operation.

For ship systems, the ship is partitioned on system lines, akin to the WBS division (FIG. 7), so systems can be given ARM target levels. However, if the hull is a system, what then is meant by the failure in ARM terms of the structure? Is it a catastrophic failure of the primary hull girder, a fatigue crack that needs repair at the next refit, or the failure of an item of secondary structure supporting minor or non-mission-essential equipment? Then again, for main ship services, is the failure of a major component, such as a pump or a generator really significant given the level of redundancy employed in a warship for survivability rather than ARM reasons? In a major multi-functional warship, ARM policy still has some way to go.

Integrated Logistic Support (ILS)

ILS brings together all the considerations necessary to assure the effective and economic support of an equipment or a system for the system's life cycle. The approach requires an ILS Manager to be appointed alongside the Design Manager under the WPM and responsible for resolving logistic questions across the whole ship, i.e. life cycle issues, training, technical manuals, provisioning of spares, special tools and documentation, and maintenance engineering. Aside from imposing a structured and integrated approach to all support issues, ILS requires instituting a thorough, detailed ILS Plan commencing at Feasibility.

The details of the ILS approach are formally stated in Reference 36 and described in Reference 37. In addition to employing standard support techniques (e.g. Level of Repair Analysis, Failure Modes Effects and Criticality Analysis and Maintenance Task Analysis), the technique of Logistic Support Analysis (LSA) is applied interactively throughout the design process. System, equipment and component designers have to demonstrate that *all* the spectrum of support concerns have been addressed. There has to be a continual dialogue between the ILS team and the design engineers *particularly in the early phases* since it has been recognized that it is then that the major decisions affecting support are made even though the design definition may be insufficient.

The ILS team will encourage trade-off decisions so that design choices are made, not just on performance and overall ship design, balance and cost considerations, but also with regard to all the support issues.

Safety Assurance

The advent of the Health and Safety at Work Act and the recognition that the designer can be held liable for the consequences of the failure of his design has provided added impetus to what has always been a major preoccupation of the naval architect as a ship designer. The ethical motivation has been amply addressed by Rawson[38] whilst Chalmers and Brown[39] discussed the issue of safety management from the stance of the naval architectural specialists.

Thus the WPM has to demonstrate there is a proper structure of safety management both in the project and set up by the main contractors. This is yet another cascade of requirements placed on the WPM to manage but unlike ILS, it is not explicitly spelt out in the Staff Requirement nor for a warship is it required to demonstrate acceptability to a classification society for structural assurance or to Department of Transport that its stability regulations have been met. Given that the overriding demands for a warship in these and other aspects

usually arise from the military environment, these commercial standards would be inappropriate. Thus the MOD usually has its own standards of safety alongside the plethora of other standards and these have to be met by the WPM. So there is an increasing recourse to a clear set of certificates defining the adequacy of the ship. The Safety Management Plan has to demonstrate safety assurance throughout the design and it has to be maintained throughout the life of the ship class.

Whole Ship Life Cycle Costing (WLCC)

WLCC provides trade-off insights in the early stages of the project and then assists the LSA work so it can be undertaken on a through-life basis. The recent provision of such a methodology for the whole ship will mean that design decisions on sub-system configurations and equipment selection will reflect the full complexity of the service life of the warship. The ability to justify 'spend to save' is a vital capability, but it is unlikely to be readily acceptable in the current cost-constrained environment. The WLCC methodology will raise more questions than it answers and these are likely to impact on the wider naval infrastructure. Thus many 'cost-effective' solutions will require the WPM to advocate additional expenditure and changes in the MOD system beyond his span of responsibility.

Risk Assessment

The separate but linked assessments of the technical, financial and schedule risks associated with any major procurement proposal have to be undertaken and presented as part of the approval process. Risk analysis tools now available in standard management systems present graphically the spread of confidence on programme and cost and the earliest, mean and latest estimates for in-service date. This highlights the risks and demonstrates where effort needs to be applied to reduce that risk. However, such approaches and tools are only as valid as the assumptions fed into the models and so the WPM and his team fall back on experience and their ability to identify what looks uncertain without being Jeremiahs. In almost any stringent financial climate a pessimistic view will lead to project cancellation which is contrary to the motivation of most project managers. Project managers are much more likely to be over optimistic so risk analysis is essential to highlight what may be unpalatable.

New Initiatives

There are several major initiatives with which the WPM already has to cope. Human Factors (HF), like ILS, is a term that originated in the USA Defence Community and it systematically tackles all the personnel-related issues. For the Royal Navy, the impetus lies in the stark realization that people of the requisite skills will not be available to man future warships to traditional levels. However, arbitrarily reducing the personnel on a given design would mean the ship could not operate as intended.

In November 1990 MOD sponsored an Industry Day[40], bringing together potential warship prime contractors and naval equipment producers with ergonomic and human factors experts. Initiatives are under way, ranging from the high technology of man-machine interfaces to focusing on design details for minimizing ship husbandry tasks. Up to now, the complement to fight, drive and sustain the ship has been derived early in the design by the naval personnel staff and then held or reluctantly increased within the ship design margins. The personnel composition necessary to operate the ship has now become an integral part of the design and the validation process. This is far more logical but has, as with ILS, some significant consequences for the management of the design.

This article, given its original audience at the Royal Institution of Naval Architects, has focused on the ship more than the weapons; however, the term warship and the title Warship Project Manager emphasize the totality of the entity that the WPM is responsible for producing. This leads on to the second initiative which is a structured approach to combat system engineering. This considers all the sensors, weapons and C^3 systems on board the warship as a single combat system[41,42].

The combat system design process starts with the scenarios in which the ship is to fight and through an analysis of the functions required of the ship's combat system, builds up a logical model of the data flows necessary to meet the functional requirements. The extensive description in the data base thus created, provides the means of managing the various component systems interfaces. It also provides the traceability necessary to produce a combat management system (the old command system) and to manage the overall system design and present it for acceptance. A task of this complexity, rigour and software intensity, is a major commitment of time and money in a new warship project and may be the only way to tackle what has become the major risk area in warship procurement[43]. Despite the fact that the combat system is of major concern to the WPM he is likely to be dependant on deep specialists and a sizeable team of software consultants to deal with this issue. Whether this structured approach is appropriate for the whole warship design task is considered in the next part of this article.

The third initiative is collaboration with other nations. It is less the laudable aim of interoperability and more the growing budgetary pressures that have led to an increased emphasis on seeking cooperation on major new weapon developments[43] and even whole new warships[44]. Whilst the NATO Frigate Replacement (NFR90) project did address the issue of standards fundamental to achieving a common ship design, it could be argued that it had not reached the really difficult stage in a collaborative exercise before the UK withdrew, on grounds of weapon and ship schedule mismatch. Furthermore, the only significant collaborative programmes for warships (the Netherlands/Germany Standard frigate and the France/Netherlands/Belgium Tripartite minehunter) were achieved in the former case with considerable differences between the two national solutions and in the latter case by one partner (France) providing both the project manager and design co-ordination. Whether or how these difficulties will be overcome in the case of the projected Anglo French Future Frigate[45] is the subject of considerable current effort both technically on the requirement, standards, and design specifics and on the procurement issues of programme, cost and project management arrangements.

The option of collaboration is bound to figure in the consideration of all future UK warship projects. Should the whole ship be a joint exercise then the skills demanded of the WPM and his team will have a further dimension of diplomacy. In particular, how design coordination is achieved through the management of the General Arrangement and of weight and space will need to be jointly agreed, as it will remain the key to design control.

Managing Future Warship Design

It is appropriate to conclude with a brief consideration of those strands which can already be perceived as being significant.

A need for Greater Exploration at the Earliest Stages of Warship Design

Since every major warship project involves vast sums of money and such projects are likely to occur less frequently, obtaining commitment to proceed is likely to be increasingly difficult. The justification behind a concept will have to be more comprehensive, both in the range of alternatives considered[46] and the

depth of consideration. The combat system will need to be integrated into the ship concept alongside operational analysis studies and WLCC. Thus, numerically based ship concept design programs will have to be succeeded by graphically based systems[16] enabling combat system integration to be considered at the preliminary level, perhaps coupled with a more visible decision-making approach[47] and accessible intelligent data bases[48].

A Need for a Greater Level of Endorsement Assurance

Assurances of reliability, support and safety with initiatives such as HF mean that all these activities must achieve their specific milestones at each of the regular approval or endorsement steps. Many are interrelated (e.g. ARM analysis, LSA and HF tasks) and require significant engineering definition to provide the assurance sought. Thus the project team will have to ensure that most of the features of the warship are designed to a reasonable engineering level much earlier in the design and procurement process than is currently the case.

Even at concept level a degree of assurance is required and by the end of Feasibility considerable definition and exploration has had to have been undertaken. This has been recognized in the US Defense Department by the move to Concurrent Engineering[49] which is illustrated in FIG. 9. This compression and overlapping of the stages of the design process run counter to the current parallel design and development of major new weapons and the ship design, where substantial design work takes place in Design Definition. Furthermore, detailed ship engineering does not occur until well into Detailed Design (FIG. 2). Advancing the design process may also mean that some of the crucial ship design debates, on those aspects that need to evolve by interaction, may be short-circuited or, even worse, given limited oversight in the pressure to demonstrate achievement of these various new endorsement milestones.

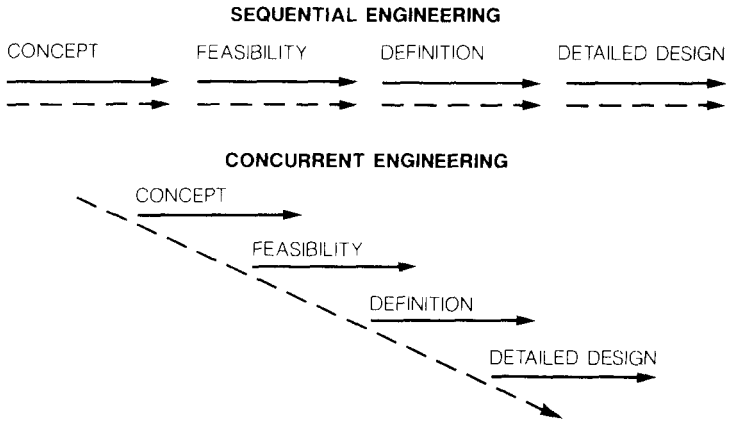

FIG. 9—CONCURRENT ENGINEERING

The Pressure to be Seen to be More Systematic in the Evolution of the Ship Design

It has been suggested that a similar approach to the highly structured and formal combat system design strategy could be adopted for the whole warship, defining every feature on a functional basis. Such an approach is similar to an unrealized 1979 MOD initiative on Functional Staff Requirements[50]. However, a functional approach is less applicable to the whole ship since:

(*a*) The conceptual justification for the overall warship is initiated by the need for ship replacement and the concept phase tackles the question 'what capability can I afford?' rather than being solely scenario driven.

(*b*) The diverse nature of the ship engineering half of the warship. Many of the 'float, move and supporting services' aspects of the ship are neither tied into precise combat scenarios nor characterized by information data flows that provide the basis for the logical analysis used to design a modern warship combat system.

Adoption of a functional basis for whole warship design will be far from straightforward, nevertheless it might still be a useful discipline, provided the limitations are appreciated and the danger of moulding the design solution to what is only strictly amenable to functional analysis is strenuously resisted. The greatest defence the WPM has to such straight-jacketing lies in continuing to employ an architectural (i.e. weight and space) overview for design management which provides the necessary control for design integration, conflict resolution and overall design coherence.

The Need to Manage an Increasingly Unstable Design Process

Despite the intentions on the combat system side to evolve the technical solution from scenarios and requirements capture, in reality the Staff's perceptions change from concept to delivery. New weapons evolve to meet changing threats and prototype systems like the Towed Array passive sonars lead to different tactics requiring different characteristics being emphasized in the ships deploying them. If the ship design was highly tuned to a given scenario and lacked adaptability then it would be far harder to accommodate the new features that arise in every design (e.g. Type 23 frigate post Falklands[3] and INVINCIBLE Class post Sea Harrier[1]). The WPM has to resist requirement changes but, given the gestation period and the growing timespan between succeeding classes of warships, such an approach may not be a good use of this major national investment or resistible given wider naval and governmental procurement pressures.

The warship is not a highly tuned weapon system, it is a collection of disparate technologies confined with several hundred personnel in a steel box, in a hostile environment. What the modern warship provides is a highly flexible and adaptable entity containing weapons and other military and not so military features. Hence the design management system must recognize this and be able to respond. Initially, the WPM has rapidly to assess the impact of modifying the requirement. Downstream he has to respond to 'what if' questions in a manner that demonstrates the full consequences of significant reconsideration. Here again, there is a clear need for responsive graphically centred Computer Aided Ship Design (CASD) systems[16].

The Need to Exploit all Available Tools

Without some straws in the wind, the relatively small and inexperienced warship project teams will be unable to cope with all the pressures. Most projects have IT systems often with micros linked in Local Area Networks. Whilst even simple word processing helps to manage the vast quantities of data, a linked system is a positive advantage for communications within the team, regularizing specification production and facilitating endorsement and tender assessment. Conversely standard personal computers provide commercial packages for project control, risk assessment, presentational data, etc. As with so much of warship project management what is required is a mix of tools and a sceptical attitude to a single overriding methodology or operating system.

Once the design form is clear, the GODDESS system[51] to a significant degree provides excellent design control by its top level auditing capability. However, it is not a straightforward system at the early stages and there is a need in initial ship sizing to bring in the architectural component (FIG. 10). The degree of

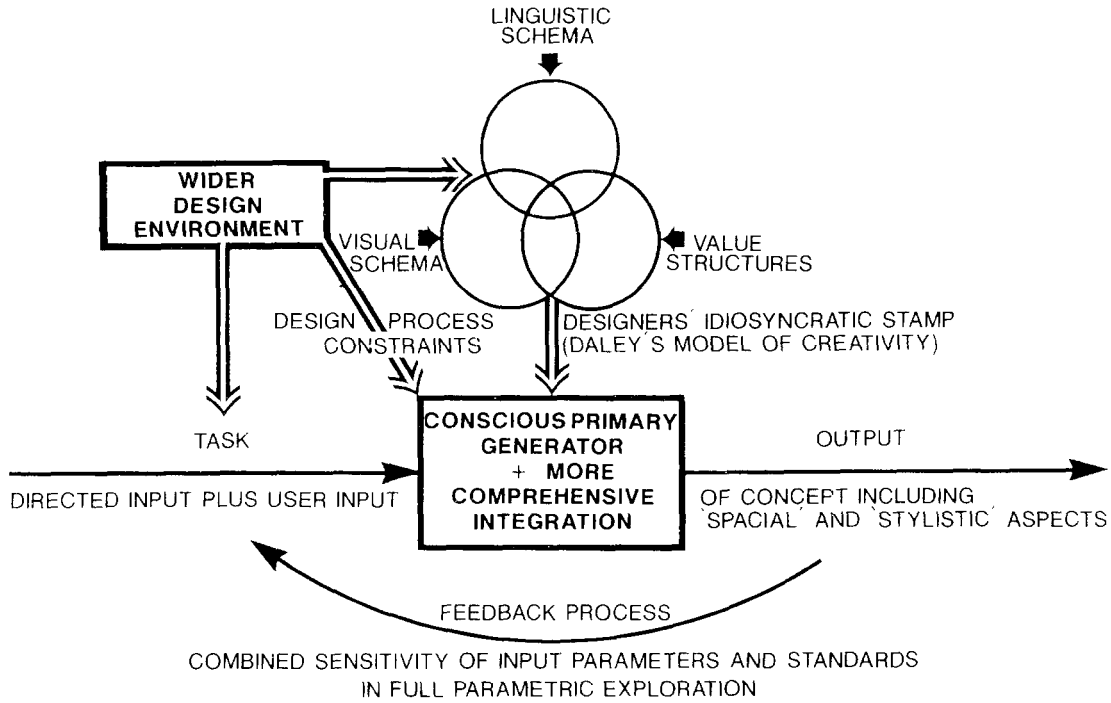

FIG. 10—A SUMMARY REPRESENTATION OF AN APPROACH TO A FULLY INTEGRATED SHIP SYNTHESIS

fluidity in the early phases of the design coupled with the move towards concurrent engineering demand greater definition earlier. It may be that a more graphically orientated preliminary design tool will emerge on the lines suggested by Ball[52] who manipulates 'building blocks' of appropriate sizes in a 3-D display to achieve a satisfactory preliminary arrangement. Alternatively, the GODDESS system could be modifid at the front end to provide a facility akin to those suggested by Thornton[53] for yacht interior design and by Kockums's CADCAM suite[54]. The ability to walk through a design would facilitate the dialogue with specialist and user departments who normally do not see the impact of their contribution to the specification until they arrive on the virtually completed ship.

People

Ultimately the WPM is dependent on his team. If the WPM is lucky he will inherit people who have dealt with precisely that ship class which the new class is destined to replace. Their wealth of experience is invaluable, but it is also important to have the team leavened with some radical beings who want to question how it was done before. So the fortunate WPM achieves a team with a mixture of talents. The WPM's professional deputies are the critical people in the team. Hopefully they are all prospective WPMs and want to get the unique experience provided by a job at the sharp end of procurement. Although the WPM has far less freedom of action than his commercial equivalents, getting your staff promoted is one sure way to attract the best talent.

One final word on the WPM. Whilst it often seems there is an excess of responsibility and a paucity of real power and authority (despite the good intentions of Jordan-Lee-Causey[55]), having responsibility for the whole warship, being seen as 'Mr Type X' has to be a pinnacle in a naval architect's professional life. In the end, whilst experience, design feel and professional ability are more than necessary, perhaps the energy and resilience that goes with complete commitment to your project is the essential stamp.

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