CHALLENGES AND ASPIRATIONS FOR MARINE ENGINEERING IN THE ROYAL NAVY

BY

COMMODORE R. F. JAMES, ADC, CENG, FIMARE, RN
(Naval Support Command, Bath)

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ABSTRACT

The article audits marine engineering in the present Fleet highlighting major developments of the recent past. The key drivers for the future are then identified and their rationale established. These are set in the context of resource forecasts together with how the Navy sees both the industrial base changing and how the interaction between customer and supplier will most likely develop. Specific technology areas such as main propulsion, controls and surveillance, damage control and environmental issues will then be addressed, and likely developments, in line with the previously identified imperatives, suggested and argued.

Introduction

The changes in the world political and strategic balance over the last two and a half years have been so fundamental that it is absolutely proper that the United Kingdom, as a major player in the Western Alliance, should conduct a re-appraisal of her defence needs and requirements. This has been done under the banner 'Options for Change' and we have now reached the stage of that process where the overall shape and size of our armed forces in the medium term has been determined and we have set about the processes necessary to achieve such a state[1]. 'Smaller but better' has been coined as describing the goal implying a reduced proportion of gross national product being devoted to defence but that better value for money needs to be obtained from such reduced resources. Given that in UK we ended the decade of the 1980s as having one of the highest proportions of GNP devoted to defence from the industrialized countries of the Western world, the pressures to reduce defence spending in light of the changed strategic perspective have been as great in the UK as elsewhere, and because such a fundamental shift in emphasis invariably brings its own associated costs, the reality is that the 'smaller' will inevitably precede the achievement of the 'better'.

We start this process with a Navy having as comprehensive an inventory of assets in the form of ships, submarines and aircraft as any country excepting the USA and the former Soviet Union. The constituents of our Fleet have been predetermined both by costs and by the primary task of being assigned to NATO in the defence of the eastern Atlantic and northern seas against the forces of the Warsaw pact. This role placed a premium on anti-submarine warfare against a steady increase in sophistication of potential enemy assets.

After the collapse of the Soviet Union and with the experience of the Gulf War as a sharp reminder, the nature and location of any future conflict in which the UK may be involved is seen as being more varied and much less certain. Nevertheless, the assets of the former Soviet Union Navy are still largely in being and cannot be dismissed from our overall defence analysis. While anti-submarine warfare may well be less predominant in the postulated mission profiles which affect the requirements for future ships and weapons, many countries possess quiet, modern conventional submarines whose presence cannot be ignored.

The size of our Fleet at the end of the Gulf War is shown in TABLE I. The Options for Change work has produced plans for a reduction in the number of frigates and destroyers to below 40 and to reduce the submarine Fleet to the order of 13 SSN and 4 SSK (diesel powered boats). The remainder of the Fleet will be largely unaffected though there will be a small reduction in the number of minor war vessels. A key feature of the future Fleet will be the continuing provision of an amphibious capability and plans have already been announced to replace the ageing LPDs (*Fearless* and *Intrepid*) and to provide an aviation support ship (Landing Platform Helicopter, LPH, in modern parlance)—a facility that has been largely missing from the Fleet since *Hermes* was withdrawn.

TABLE I—*Size of the Fleet at the end of the Gulf War, 1991*

SUBMARINES			
Polaris			4
Fleet SSN			14
Type 2400			1
'O' Class SSK			7
SURFACE FLEET			
ASW Carriers (INVINCIBLE Class)			3
LPDs	(FEARLESS Class)		2
Destroyers	Type 82		1
	Type 42		12
Frigates	Type 23		2
	Type 22		14
	Type 21		6
	LEANDER		12
Offshore Patrol Vessels		CASTLE Class	2
		ISLAND Class	7
MCMVs		TON Class	9
		HUNT Class	13
		RIVER Class	12
		SRMH	2
Patrol craft			21
HMY *Britannia*			1
Ice Patrol Ship			1
Survey Ships			7

The reductions from the Fleet quoted in TABLE I to reach the post Options state will be achieved by the middle of the decade. They involve the withdrawal of most of the older frigates and destroyers (predominantly the LEANDER Class), some of the older nuclear submarines, all the older conventional submarines of the O and P Class and the wooden hulled minesweepers of the TON Class.

One effect of this will be the virtual demise of steam as a propulsion medium for surface ships, leaving only the LPDs and HMY *Britannia* in service beyond 1994. Although gas turbine and diesel propulsion have been used in the Navy for many years, it was not until 1987 that more miles underway were achieved by gas turbine than by steam propelled surface warships (FIG. 1). The subsequent run down in steam propulsion in the Royal Navy has been rapid.

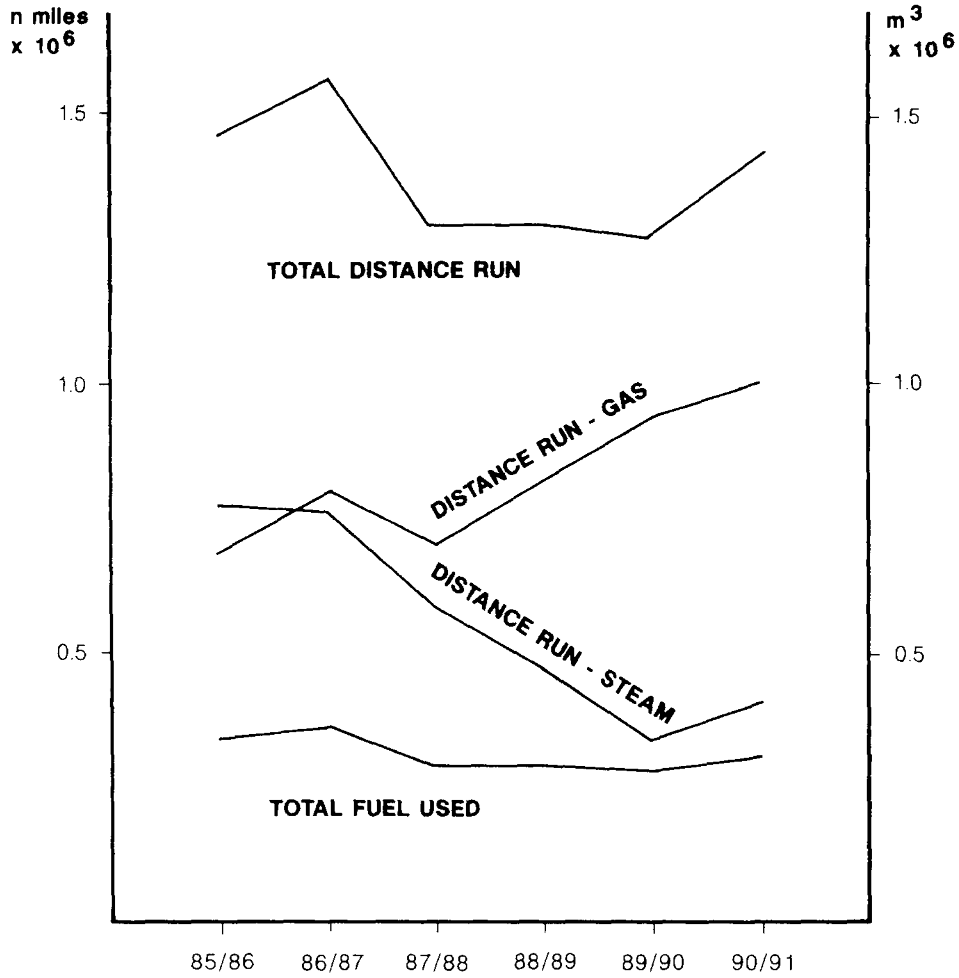

FIG. 1—DISTANCE RUN AND FUEL USED

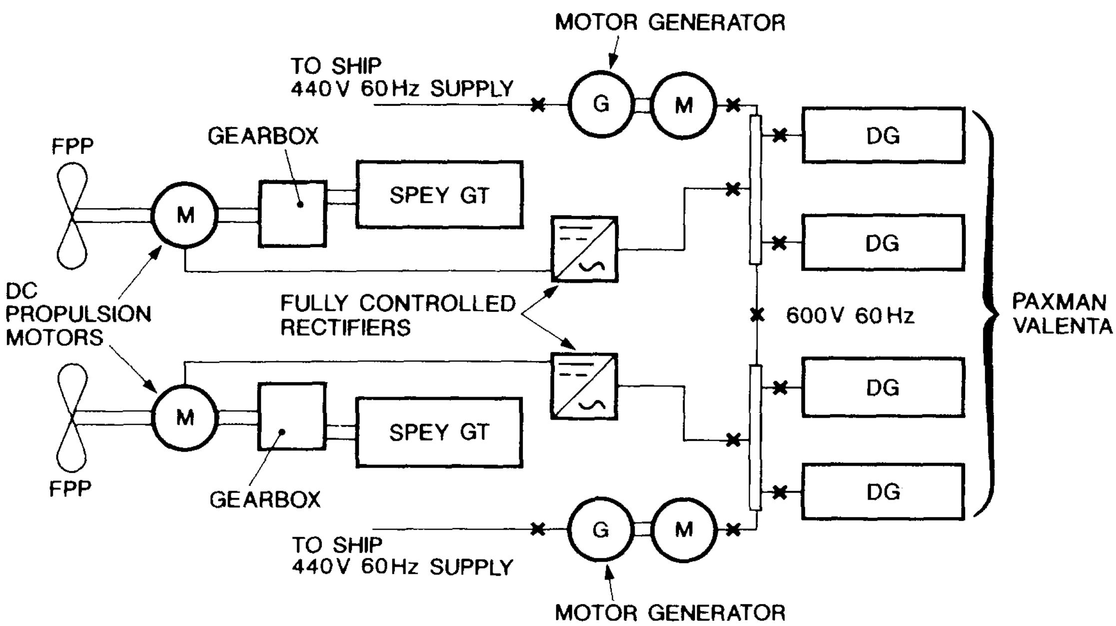

FIG. 2—TYPE 23 FRIGATE CODLAG PROPULSION

Marine engineering in the immediate post-Options Fleet will be characterized in the following ways. The major elements of the surface fleet will be propelled either by aero-derivative marine gas turbines entirely or, in the case of the Type 23 frigates, in conjunction with electrical drive (FIG. 2)[2]. The more modern ships will have made the change from analogue surveillance systems and separate but parallel hard wired control systems, to an integrated digital control and surveillance system using a distributed microprocessor-based system with hard wiring restricted to only the most critical control functions (FIG. 3). A variety of transmission systems will be in service from the complex reversing gearbox of the INVINCIBLE Class to the use of a DC electrical motor integral with the main shaft line to provide both low speed cruise and astern power in the Type 23 frigates. However the majority of the frigate/destroyer fleet will be fitted with CPP transmission systems. High quality electrical power of 60 Hz as required by sophisticated weapon systems will be generated by high speed diesel driven generators in units up to 1.5 MW. In most ships the practice is to run generators on a split distribution system but in the case of the Type 23 Class, parallel running has been introduced for the primary power generation at 600 V. In all surface ships the design of ship systems, auxiliary machinery and damage control arrangements will reflect an evolution towards the concept of zoning into a series of self-containable but interconnectable sub-divisions of the ship.

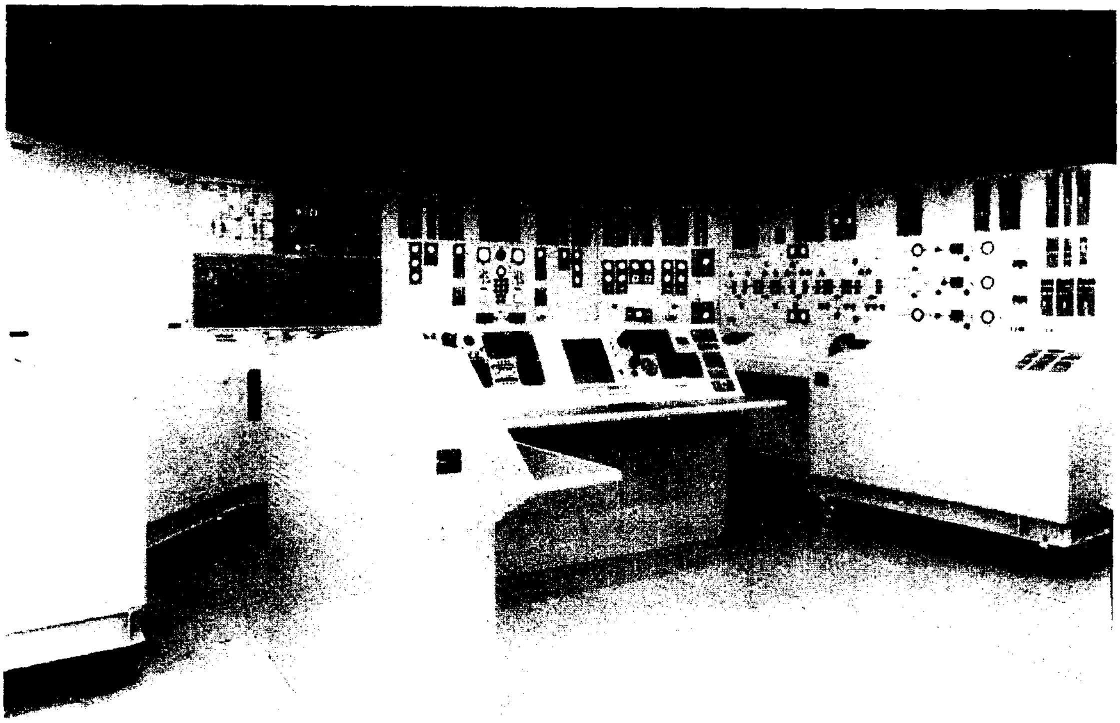

FIG. 3—TYPE 23 MACHINERY CONTROL CONSOLES

The minor war vessels of the Fleet vary from the relatively simple off-shore protection vessels to the small but highly sophisticated mine warfare fleet. All are diesel powered and in the case of the mine warfare vessels the characteristics of the marine engineering systems are dominated by the mission which dictates critical facets such as magnetic signature and position keeping requirements.

The nuclear submarine fleet is all powered by pressurized water reactors and steam propulsion plants. The design evolution of successive classes has concentrated on measures to lower the overall signature of the vessel (predominantly in the field of noise) to improve availability through increased refit interval by detailed changes to system design and by selection of more durable materials and to increase safety margins in line with national standards. Achievement of the potential of very long submerged endurance calls for the level of environmental quality within the vessel to be sustained. To effect this, the latest submarines reflect significant advances in the engineering of systems for atmosphere control.

The non-nuclear submarine fleet will consist entirely of the modern UPHOLDER Class in which the battery/diesel power plant is traditional in concept but has been modernized and upgraded to support the weapon systems which are much more advanced than any carried by a previous Royal Navy conventional submarine[3].

Industrial Base and Procurement

Almost all the marine engineering equipment fitted in the immediate post-Options Fleet has come from British industry. Whilst this has been the traditional source of supply, the British government has been in the van in moves to open up defence equipment markets throughout the European Community. However, whilst our requirements have been more widely broadcast, there has been as of yet little effective penetration of the UK warship market by European industry. This may in no small part be due to the highly competitive position of this section of UK industry—as evidenced by the export records of many companies. But it should not be assumed that either the Ministry or its prime contractors will continue to buy British if such a practice does not give value for money.

The keystones of our procurement policy can be summarized in the three 'c's:

- contractorization;
- competition;
- collaboration.

Contractorization means that government bodies should limit themselves to only those tasks which by their nature it is essential for them to perform with intra-mural resources. The effects of this policy are diverse, but include giving the defence research establishments agency status as the Defence Research Agency which will shortly be in a position to compete with Industry for certain tasks. Other effects have been the placing of greater risk with industry though giving prime contractors a more significant role in the design of ships and systems. Many post-design engineering issues in support of the running fleet are now handled by industry and the trend is to seek greater involvement of the devolved design authority during the in-service phase. The process of giving more of the procurement and support activity to the industrial base is likely to gather momentum as intra-mural resources reduce as part of the Options for Change restructuring.

The emphasis on competition will be well known to all who have been involved in recent years with defence procurement in UK (FIG. 4). Suffice to say, there is ample evidence that it has brought value for money and may be assumed to remain a cornerstone of procurement policy for the future. As both suppliers and the Ministry of Defence as customer become more accustomed to the practice it will undoubtedly become more refined and sophisticated in application.

Collaboration is seen as a valuable way of sharing development costs, obtaining some benefits of scale from increased production runs and drawing on a wider industrial base. Given that ships, as opposed to the weapon systems fitted to them, have relatively low development costs and that unit production costs for warships will probably not change significantly in the numbers normally being considered (i.e. an average of less than ten ships per nation), it is perhaps not surprising that experience worldwide in collaborative warship projects is very limited. There are prizes to be won but these require close alignment of operational requirements, timescales and procurement strategy. It is most likely that the UK will strive to gain the benefits of collaboration in appropriate circumstances. However, where the circumstances are not appropriate the lessons of the NATO Frigate Project serve as a deterrent to collaboration[4].

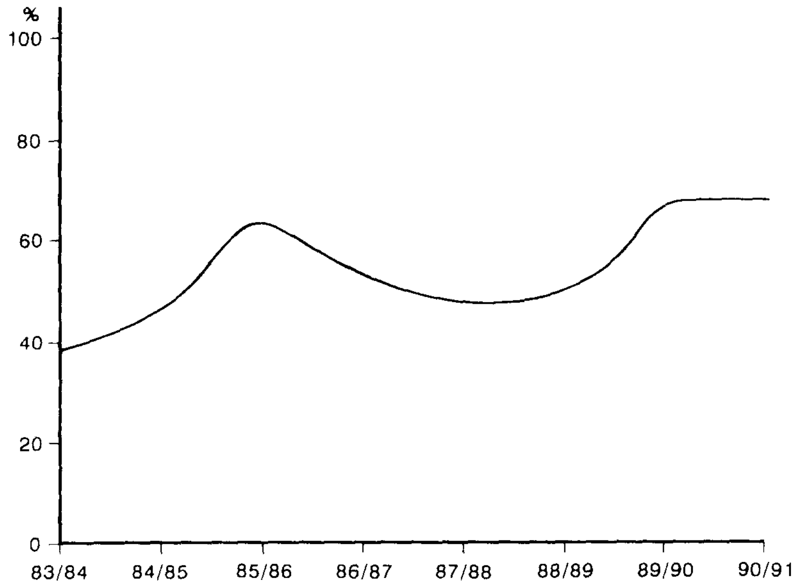

FIG. 4—THE SHARE OF TOTAL VALUE OF CONTRACTS PLACED BY COMPETITION. FIGURES INLCUDE USE OF COMPETITIVE TENDERING PROCEDURES AND COMMERCIAL PRICE LISTS

Resources for the Future

It is most important that the resources to achieve the 'better' of 'smaller and better' are most clearly directed. As already indicated activities such as consolidating real estate and training facilities frequently require up-front investment so that, as the whole of defence reduces in size, resources for future equipment and system development will inevitably become squeezed. This means that Ministry of Defence funded technology development of a more speculative nature will not be justifiable and that resources will only be set against those areas where a military need has been very firmly established. Most marine equipments fitted in warships have a close relationship to commercial counterparts and few equipments are designed specifically and totally for warship application. But whereas a technology may be being marketed for a variety of potential applications, there may well be a need to verify its suitability for translation into the warship environment through discrete development work or a technology demonstrator before it can be called up in a statement of requirements for a particular project. Because it is not practical on grounds of either time or cost to invest in development prototypes for warships, it is vital that the customer and supplier, both of whom will carry some of the risk, have confidence in the suitability and fitness for purpose of the equipments and systems being prescribed. Thus the development resources that are available will, for the foreseeable future, be very closely focussed on deriving confidence in particular solutions for a firmly identified need.

Drivers for the Future

Given the strategic background and the forecast of the availability of resources for development work in the field of naval marine engineering in the medium-term future, what are the imperatives to which these resources should be directed?

Through-Life Cost

Undoubtedly the greatest is cost of ownership. The through-life costs of a warship are very large and typically a figure of three times acquisition costs has been estimated as the post-acceptance cost of a frigate type vessel. Much attention has been paid over the last quarter of a century to reducing unit procurement costs of warships through efforts in the field of shipbuilding practice, design and, not least, the contracting policy with competition as a cornerstone. Less attention has been spent on ensuring we get as good value for money during the in-service phase. Opportunities for better value after acquisition have been highlighted in recent parliamentary investigations by both the Public Accounts Committee[5] and the House of Commons Defence Committee[6]. Major initiatives are under way on three fronts:

- contracting for improved reliability;
- greater visibility to support issues being given at the design stage through the disciplines of integrated logistic support (ILS);
- greater emphasis being placed on through-life costs at the design decision stage.

One common feature of these initiatives is that, whilst they are aimed at reducing in-service costs, their effectiveness will only be optimized if they are applied as early as possible in the acquisition process (FIG. 5).

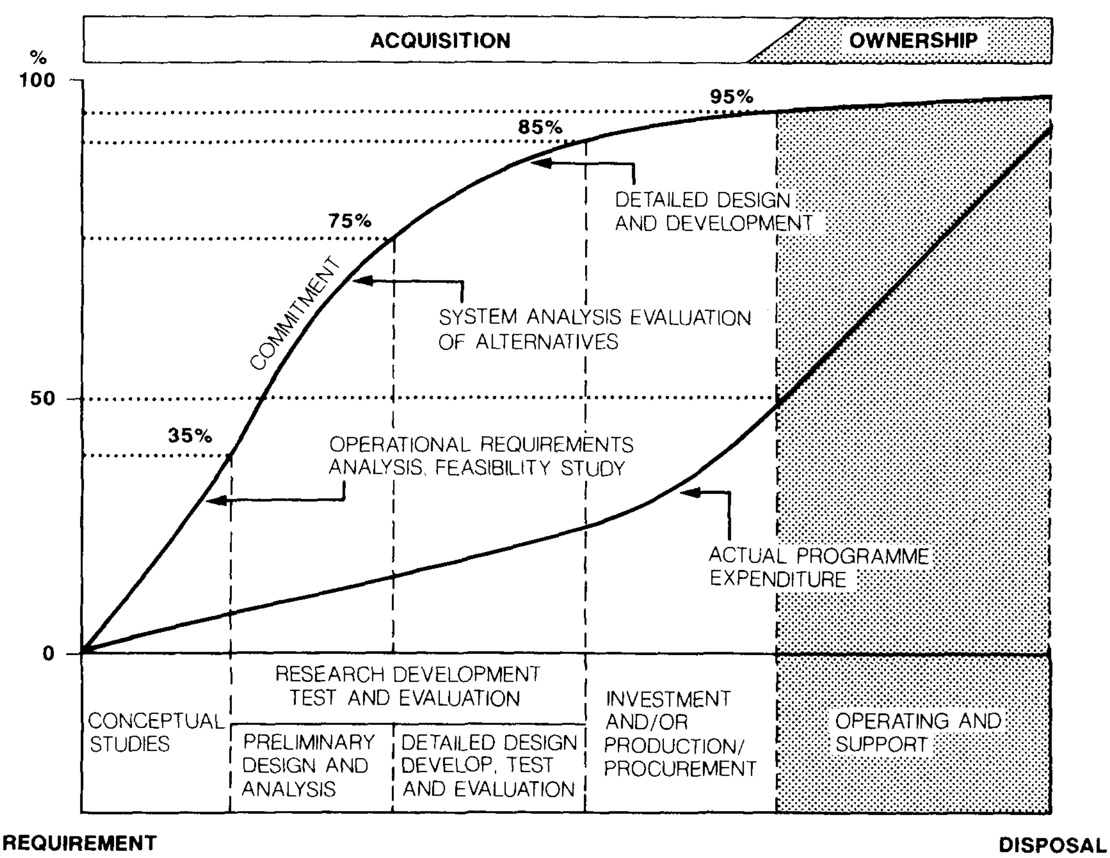

FIG. 5—INFLUENCE OF PROGRAMME DECISION STAGE ON LIFE CYCLE COSTS

It has been estimated that unreliability costs the Ministry of Defence some £1bn per annum and a drive has been put in place to reduce this figure by half. Reliability targets are being much more specifically defined in requirements, and many contracts now require reliability demonstrations and for the contractor to underwrite achieved reliability in some way. The classic numerate interpretation of reliability based on Mean Time Between Failure, Mean Time to Repair, etc., does not sit easily in the whole warship context though it can apply quite readily to some marine engineering requirements such as gas turbines and diesel generators. Because of their relatively small numbers and complex array of systems and sub-systems, an approach centred on the achievement of availability targets is more appropriate for warships. There is no question however of them being exempt from this particular initiative to reduce the cost of ownership.

Integrated Logistic Support (ILS) is a particular practice developed in the United States and defined in Mil Standard 1388[7]. Its purpose is to cause support considerations to be integrated into system and equipment design and to develop support requirements that are consistently related to design and to each other. Whilst the Ministry has had long-standing guidance on the provision of support for ships and their systems in the Management of Design for Upkeep and Support (MANDUS) which enshrines many of the tasks of ILS, the difference is the discipline which is imposed by the latter within the design process which should firmly prevent support issues being undervalued as the inevitable pressures of time, costs and performance affect projects. However much work remains to be done to adjust the practices of Mil Std 1388 to the UK procurement environment and to provide detailed guidance on how to implement the concept. A further development in this field is Computer Aided Acquisition and Logistic Support (CALS) which provides the rules for the electronic formatting of logistic support and this is being considered as a complement to ILS. Before this practice can be invoked consensus needs to be achieved on data exchange standards. Whilst ILS and its associated developments hold out the promise of producing a more structured and therefore more cost-effective route to putting support in place, great care must be exercised that they are developed with sufficient flexibility to avoid an overbearing bureaucracy being put in place.

For some time now the stated intention has been to take account of through-life costs as well as unit procurement costs in the acquisition process. Whilst greater emphasis on investment appraisals has undoubtedly advanced this intent, further progress has been inhibited because the tools with which to develop a through-life cost appraisal have not been sufficiently sophisticated. The MOD has been working for some time now on developing a hierarchy of models on which to make through-life cost judgements and comparisons. At the lower level are a set of models appropriate to equipment and systems in specialist areas and these will support a whole ship life cycle cost model. One of the equipment models has been specially developed to cover marine engineering equipments and systems (acronym MECCA) and validation of this model is well advanced. At present it is only available for use within the Ministry but the intention is to make it available for use by industry as has been done with its weapon counterpart, SEALECT. A whole ship model presents a considerable challenge in both production and validation but good progress has been made and one is already being used internally as an aid in evaluating proposals for new classes. The need to give greater weight to through-life cost considerations is firmly recognized but its impact will depend on the credibility that such costing attains, which in turn is dependent both on the stature of the models and the quality of cost feedback. This should be greatly enhanced through the working of the Ministry's new Management Strategy[8].

The predominant ingredient of cost of ownership with present warships is the

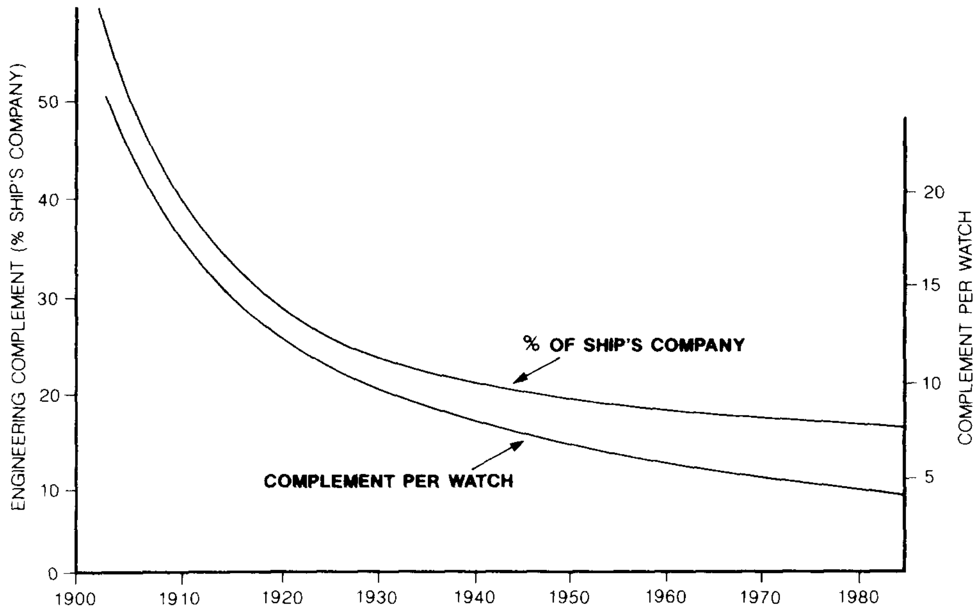

FIG. 6—MARINE ENGINEERING COMPLEMENT OF FRIGATES AND DESTROYERS

manpower cost and this, coupled with the demographic trends in the United Kingdom, will ensure that close attention is paid to the manpower bill. Modern COGOG or CODLAG frigates require a significantly smaller marine engineering complement than their steam predecessors (FIG. 6). However we can expect the drive to reduce the manpower bill both quantitatively and qualitatively. The reductions previously achieved have been largely in the field of the watchkeeping load, but in modern warships the determinant for the marine engineering complement does not necessarily lie in watchkeeping tasks alone but rather in a complex conjunction of watchkeeping, maintenance, general ship safety, action damage control and other duties. Thus in future no single measure is likely to release a significant proportion of present day complements but rather the problem must be tackled on a broad front. Some de-enrichment of the manpower is a likely outcome of present studies. Such a move would release the most highly skilled from watchkeeping duties and allow them to concentrate on diagnostic and deep skilled maintenance. One way of reducing cost of ownership is to achieve greater utilization from the man and this requires more detailed attention to human factors in all facets of his duties. Initiatives are under way to develop further guidance and criteria for ensuring that human factor issues are addressed with sufficient prominence in the design process.

Electrical Power

Up till now the design of warships has treated the provision of propulsion power and the distribution of ship service power as interrelated but separate functions. This separation has become less marked in the Type 23 frigates in which both propulsive and ship service electrical power are generated by the same set of prime movers supplying a common bus. At the same time, as indicated in TABLE II, the total connected loads of warships have increased over various class gener-

TABLE II—*Comparative growth in total connected electrical load*

LEANDER Class (Batch I)	1927 kW
Type 21 frigate	2760 kW
Type 22 frigate (Batch I)	3900 kW
Type 42 destroyer	3720 kW
Type 23 frigate	4240 kW
TON Class (minehunter)	460 kW
HUNT Class	664 kW

ations and thus ship (including weapon) loads are assuming a more significant proportion of the total energy requirement. Active sonars already demand large pulse peaks of power and should, as is quite likely, the next generation operate at lower frequencies then pulse peaks will become more dominant. In addition, should the present development work on pulse energy weapon systems lead to their ship-borne installation then accommodating power peaks would become one of the main engineering challenges in the marine engineering system design. All this points to a philosophy of total energy management as becoming a dominant design issue, which in turn will greatly influence selection and numbers of prime movers and power transmission systems.

Controls and Surveillance

Much of the reduction in the watchkeeping manpower load has come through the development of ever more sophisticated machinery controls and surveillance systems culminating in the current digital systems fitted in Type 23 (FIG. 3), Single Role Minehunter, TRIDENT and UPHOLDER Classes. However in a typical Ship Control Centre, e.g. Type 23, the machinery controls and surveillance are really totally separate from the management of the other ship systems particularly those associated with safety and damage control. The level of sophistication attached to these other systems often lags considerably behind the machinery controls technology. In the midst of an array of plasma screens, compartment keys are still controlled and issued in a manner reminiscent of a medieval warder. A major imperative in the overall management of the ship is to invoke some of the technologies so successfully used in the machinery controls area in these other fields to produce a much more integrated whole ship management system. Such initiatives may be one way of further reducing the manpower requirement. A significant factor which will determine the way ahead will be the status accorded to internal communications. As fighting a ship becomes more complex so does the role of internal communications which play a vital role in three major areas:

- at the interface with external communications, where the need is to provide as integrated a facility as possible;
- as an integral component of effective damage control and ship system management;
- as a complement to the combat management system.

A smarter generation of internal communication systems will be needed to match these demands.

The Environment

Environmental issues are having a greater and greater effect on ship design and marine engineering plant management. For many years government policy was that even where exemption could be claimed, every reasonable attempt should be made for all MOD-owned vessels to comply with environmental legislation and regulations. Recently the pressures on the Navy have measurably increased in this respect for three main reasons:

(*a*) The UK government has intensified awareness of green issues within its various departments.

(*b*) Various recently introduced measures such as Montreal protocol regulations are being enacted in such a way that blanket Crown exemption is not possible[9].

(*c*) Many local regulations and sub-national legislation impose demands which far exceed either UK or international rules and have large cost implications for ship visits to foreign ports.

Compliance in the warship situation is seldom easy. The high density of population and lack of spare space make it particularly difficult to meet not only the MARPOL regulations on oil pollution, garbage and sewage, but some ports now not only forbid discharge of grey water but also do not allow even clean discharge to better than IMO standards from sewage plants[10].

The Montreal protocol and its subsequent revisions have not only a considerable effect on the choice of refrigerant used in air conditioning and main fridge plants but also affect the whole practice of firefighting where Halons have become established as the preferred medium for firefighting systems in machinery spaces and other key compartments. The combination of fire suppressant qualities and lack of toxicity is so far unrivalled, and finding an acceptable alternative presents a great challenge to both the Navy and to industry.

The most recent environmental issue which presents a formidable challenge in the warship situation is that of emission control from internal combustion prime movers. Apart from cost grounds, heavy and bulky exhaust control devices are an unattractive prospect on account of the effect on topweight.

With the possible exception of MARPOL, these environmental issues have become pressing over a timeframe markedly less than the life cycle timescale for a class of major warships. Compliance is quite clearly more readily achieved if addressed at the design stage. In order to succeed in this respect a longer term perspective of trends on environmental pressures needs to be developed, together with a complementary strategy for producing designs which are not only compliant with today's regulations but are readily adaptive to those of the future.

Safety

Safety issues are assuming greater significance in the challenges facing marine engineering in the Royal Navy. The practices of the last 100 years have evolved from reliance on senior professional officers having a detailed control over the design process to a situation where greater reliance on the achievement of standards has been given to project staff, for it is judged that they alone can manage the whole array of inputs and demands and can act coherently as the customer, as more and more is devolved to industry. In the past, reliance on embedded professionalism was absolute and there was little formal recognition of safety issues with the notable exception of the requirement to issue a stability statement. Although this professional culture has served the Navy well, the combination of:

- the introduction of the functional project manager,
- the Inquiries into recent major disasters in which much attention has been placed on the evidence of strong effective management of safety emanating from the top of the organization concerned[11],
- the repeal in 1987 of Section 10 of the Crown Proceedings Act so that servicemen (or their dependants) can now seek redress in the courts for negligence sustained in the course of their duties,

has focussed attention on the need to create a formal ship safety management system.

Fundamental to such a system are a number of key features:

(*a*) the creation of a top-down safety culture embodied in the formal structure for the management of safety;

(*b*) responsibility for achievement of safety placed unambiguously on the project, or operator line management;

(*c*) clear lines of communication through formal letter of delegation of authority for safety to named personnel;

(*d*) establishment of a high level Ship Safety Board;

(*e*) a separate body to set safety engineering standards and to audit safety management;

(*f*) a selective regime of formal certification for safety.

Of particular concern to those operating the system will be the management of what are deemed to be critical ship safety hazards, which are defined as those which could lead to catastrophic damage to or the loss of a ship with associated major loss of life. Included in this category of safety hazards are:

- loss of stability;
- structural failure;
- explosion of own armament stores;
- loss of watertightness;
- fire;
- toxicity;
- escape and survival.

This greater emphasis on the management of safety will of necessity influence the design and procurement process of marine equipments and system for naval service.

Future Equipment Developments

The scope of this article is too broad to introduce a full justification for every possible line of material technology development that is possible or even likely to arise from the drivers that have been discussed and, as already stated, resource constraints will mean that the need has to be very soundly justified before development funding can be committed. However, certain particular topics present themselves as strong contenders for inclusion in the future programme.

For the main elements of the surface fleet the predicted operating profile may well indicate a more general purpose operating regime than that used in the Type 23 frigate design which was biased on anti-submarine warfare. Such a change in emphasis would lead to an increase in the cruise power requirement, maybe even to the region of 5 MW per shaft. This, coupled with the move towards total energy management, could tilt the balance in favour of electrical transmission systems but at these powers there would probably have to be a shift to AC from the DC drives used in the Type 23. The technology for such systems has already been proven in merchant ship installations but there would be a need to conduct discrete development work to prove the suitability of the technology for warship applications. It is presumed that, as in the Type 23, the opportunity would be taken to combine cruise propulsion prime movers with at least some of the generator capacity. These prime movers could either be taken from the currently existing range of high speed diesels employed in multiple or be a new-to-service gas turbine of around 5 MW capacity. For high speed diesels to be the more attractive it would be most desirable to see a further reduction in maintenance costs which are closely related to the number of cylinders deployed. Acceptable diesels will also need to achieve lower noise signatures through the development of more sophisticated mounting arrangements or by tackling the problem at source through component design. The diesel engine system designers are however facing a major challenge from future exhaust emission regulations and the possible solutions being proposed for merchant vessels would probably be inappropriate or unacceptable in a warship.

As an alternative to diesels the gas turbine has potential. Already firmly established in the power range in excess of 5 MW in simple cycle form, complex cycle variations of high power marinized aero engines are now being offered. Although these complex cycle engines offer attractions there is a space, cost and weight penalty compared to the simple cycle variant.

It may be that the greatest benefits in moving away from the simple cycle would come in developing new generation engines around the 5 MW capacity employing at least some elements of the complex cycle and which could be relatively competitive with high speed diesel engines in through-life costs. Such engines could be readily derived from the core components of engines of much higher output already developed and would be more amenable to emission regulations than diesels since the simple cycle unit is already better placed in this area.

Where mechanical transmission systems are used the choice lies between reversing gearboxes and controllable pitch propellers. Both are proven technologies. As far as reduction gearing is concerned, there is a continuing need to refine design codes to give greater confidence in the margins that result in any given design and to show the way to achieve lower noise signatures. Reliability improvement would be most welcome in the field of stern seals and underwater bearings and development effort will be directed in this area.

As far as submarines are concerned, any future nuclear-powered class will almost certainly contain a power plant which has evolved closely from the latest current designs. For any future non-nuclear boats, diesel electric power will remain a very strong contender. Recently the claims of various air-independent systems to power submarines have become more pressing. In assessing the practicality of such systems it must be remembered that at best they can enhance the performance and endurance of conventional boats but in no way can the present technologies compete with nuclear power in providing a vessel with true submarine capability. Development of any of the competing air-independent power systems will depend entirely on whether a clear need is identified.

Machinery and other platform system controls and surveillance will almost certainly develop along a line of open architecture and totally distributed systems bringing the whole together into what has been termed integrated platform management. Such a system will require close links with non-real-time engineering support and analysis systems, particularly those elements associated with condition monitoring and assessment.

As far as auxiliary and general ship systems are concerned, future developments will be directed either in support of new main propulsion and energy distribution systems or in picking up new technologies and practices which show promise in meeting any of the imperatives discussed earlier. Greater emphasis in ship design on zoning to reduce vulnerability may demand development attention in producing ship systems that are more readily divisible than has hitherto been the practice.

Conclusion

In the light of changes in the world strategic scene and the complementary pressures on resources devoted to defence (the peace dividend), there has been a perceptible shift in emphasis from the use of technology to meet ever-advancing threats to using it to provide better value for money from the resources devoted to defence. This is as true in the field of marine engineering as in any other. The resources that are available for deployment of new systems will have to be even more specifically targeted against prioritized needs than ever before; only thus will the Royal Navy be able to achieve a Fleet in being which genuinely meets the challenging target of 'smaller but better'.

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