PERSONAL

File
- Short Fat Ships

W G Sanders Esq
Director General
Future Material Projects (Naval)
Room 301
Benbow House
Emerson Street
LONDON
SE1 9EJ

2 July 1985

Dear Mr Sanders

SHORT FAT SHIPS

The other day, I offered to let you have any material on the way this subject is being pursued. I enclose a booklet by Thornycroft, Giles & Associates, which sets out the claims of the short fat design. No doubt the claim that savings of £300-450mpa will attract some attention in the context of the "hard up" Navy.

The "review" which Lord Hill Norton and associates are conducting may make something of the reply which Mr K J Rawson gave to Mr Garwin on 13 April 1981 on the Osprey/Sirius concept, to the effect that favourable results on a 1/25 scale model were irrelevant to the performance of a full-size ship because "lift increases as the square of the length, while displacement increases as the cube". This would mean that a full-size ship would have 25 x 25 = 625 times the lift, and 25 x 25 x 25 = 15,625 times the weight.

Garwin argues that this line of argument overlooks the fact that model tests are done at a speed scaled by the square root of the length scale factor, ie at 1/5 speed. Since lift varies as the square of the speed, a full-size ship would have 15,626 times the lift, and the weight, of the 1/25 scale model. Mr Rawson's reply of 22 September 1981 seems to acknowledge this point.

This correspondence, if presented in a certain way, could make it look as if the MoD naval architects at first dismissed the Osprey/Sirius concept as being contrary to the laws of hydro-dynamics, and are subsequently persuaded that the concept is a sound one.

I hope this is helpful.

NICHOLAS OWEN
Policy Unit

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DBOABW

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Ships.

The Procurement of a Warship

by Admiral Sir Lindsay Bryson, K.C.B., B.Sc., F.Eng*

Read in London at a meeting of the Royal Institution of Naval Architects on June 7, 1984, The President, Admiral Sir Anthony Griffin, G.C.B., in the Chair.

SUMMARY: The design of a warship whether it is a minehunter, aircraft carrier or a nuclear submarine is preceded by definition of its intended capabilities. The capabilities of Royal Naval warships stem from an assessment of the threats facing the United Kingdom, a member of the NATO alliance, and the Government's maritime strategy.

The paper summarises Britain's maritime strategy and describes the roles required of the many elements of the Royal Navy. Anti-submarine warfare is a primary role; the associated ship and weapon characteristics are defined. The weapon capabilities needed to conduct anti-air and anti-ship warfare are reviewed.

The paper discusses the procedures for formulating Naval Staff Requirements both for ships and weapons and describes, in general terms, the progression from concept studies of a future warship to the placing of the contract. It sets out the decision-making process and emphasises the need to take cost into account at an early stage.

The designs of some classes of surface warships in service with the Royal Navy are examined to explain how they were designed to fulfil their specified roles. Brief mention is made of some designs which failed to leave the drawing board.

The paper describes the design process in more detail by recording the conception of the latest class of anti-submarine warfare frigate, the Type 23 frigate. Its design to minimise ship radiated and self noise and to optimise the advantages of towed-array sonar is considered. The role of the helicopter and its impact on ship design is explained. The incorporation of lessons learned during the Falklands Campaign is covered.

Other designs were considered, which would have conferred different characteristics, before the Type 23 design was frozen. The factors involved in reaching the final decisions are reviewed.

The paper concludes with some thoughts on the developing scene of Naval procurement.

1. INTRODUCTION

Over the last two years there has been considerable public and press interest in the way in which warships are designed and built. This interest was naturally enhanced by the Falkland Islands operations which once again demonstrated the strengths and weaknesses of maritime power. This welcome interest has also shown that there is much misunderstanding about the process; the genesis of this paper was a desire to clear up some of that misunderstanding by describing the general approach as it operates to-day, showing how this has changed since the end of World War II and illustrating principles by using the new Type 23 Frigate as a specific example.

The general principles apply to submarine as well as surface ships and indeed to weapons systems, albeit with some essential differences which will be described. They are modified when procuring auxiliaries and smaller ships and this will be touched upon briefly. Part of the misunderstanding concerns the responsibility for the design: in the strictest sense the responsibility for specifying what the vessel is required to do rests with the Naval Staff. The warship departments at Bath and in London in conjunction with Industry and Defence research establishments produce illustrative designs to show how the requirements can be met. It is, of course, a highly iterative process which, whilst starting with the Naval Staff in the Ministry of Defence, also involves Constructors, Scientists and Engineers within the Procurement Executive of the Ministry of Defence and Industry embracing shipbuilders, weapon contractors and specialist consultants (Fig. 1). They are all part of the process of assessing the trade-offs necessary to attain a desired operational capability within the constraints imposed by the available resources of money and men.

One of the problems faced by those carrying the responsibility for the design of warships is the wide-spread belief held by those absolved from such responsibility, be they politicians or media men, that they could do the job much better. David Brown in his history of the Royal Corps of Naval Constructors$^{(1)}$ quotes:

> 'Throughout the century, the credibility of the Royal Corps has been challenged by the amateur inventor claiming to be able to design ships which are smaller, cheaper, more heavily armed and faster than those designed in the Admiralty. The classic riposte came from the great Italian architect, Benadetto Brin, before the First World War, in response to a 'design' from Kaiser Wilhelm II:
>
> 'The ship which your Majesty has designed would be the mightiest, most terrible, and also the loveliest battleship ever seen. It would have a speed which has not yet been attained, its armour would surpass that of anything now afloat, its masts would be the highest in the world, its guns would outrange any others. And the inner appointments are so well arranged that for the whole crew, from the Captain down to the cabin boy, it would be a pleasure to serve in her. This wonderful vessel has only one fault; if she were put into the water she would sink like a lump of lead!'.

However, before looking at the design process and how we strive to avoid such catastrophes, this paper will briefly review Britain's Maritime strategy and the operational

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*Controller of the Navy,
Ministry of Defence,
Whitehall, London

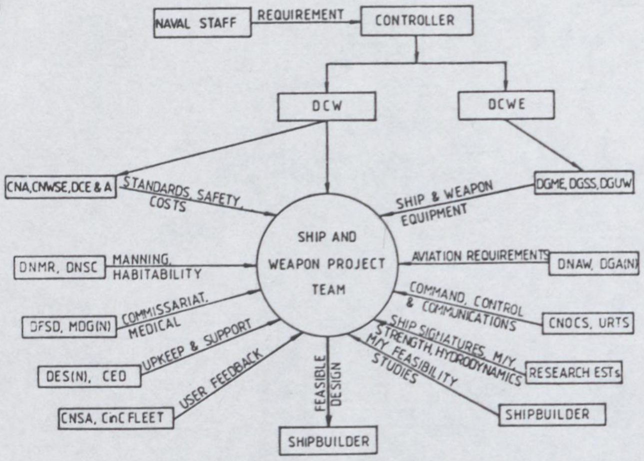

Fig. 1. Some of the authorities involved in the Type 23 design

capabilities needed to meet the various roles which the Royal Navy is required to perform. An explanation of the abbreviations used in the paper is given in Table I.

TABLE I. Table of Abbreviations

AAW	Anti air warfare
ASW	Anti submarine warfare
ASV	Anti surface vessel
TA	Towed array
VSTOL	Vertical short take off and landing
REA	Radar echoing area
CASD	Computer aided ship design
NST	Naval staff target
NSR	Naval staff requirement
CPS	Cardinal point specification
FRC	Fleet Requirements Committee
NPC	Naval Projects Committee
ORC	Operational Requirements Committee
DEPC	Defence Equipment Policy Committee
RFA	Royal Fleet Auxiliary
STIR	Surveillance and target indication radar

2. THE ROLES FOR BRITAIN'S DEFENCE FORCES

The roles have been stated in recent White Papers as:

(a) Operation of strategic and theatre nuclear forces committed to NATO.

(b) Defence of the UK Base.

(c) A major land and air contribution on the continent of Europe.

(d) A major maritime effort in the Eastern Atlantic and Channel.

The main thrust of British defence policy and the focus for the bulk of our defence effort is NATO. But both the UK and her NATO partners have acknowledged threats to their security which may arise outside the NATO area and the opportunities that exist there for the expansion of Soviet interests, at the expense of our own. NATO members therefore have agreed that we need to look beyond the European area and recent events have lent emphasis to this.

In the case of the United Kingdom, we have the additional commitment of national responsibilities outside the NATO area, in the defence of which we may have to play a role. In furtherance of this, and other national interests, we need to provide military assistance to help our friends to help themselves, to have the ability to deploy our forces widely to encourage our friends and finally, we need, as events have recently shown, the ability to deploy forces in the last resort for operational reasons conceivably at considerable distances away. This puts a high premium on flexibility and the ability to react to the unexpected.

3. THE OPERATIONAL TASKS FOR THE ROYAL NAVY

3.1 National and NATO tasks

The operational tasks for the Royal Navy are derived from these UK defence roles and underpin the design of our Naval Forces and their constituent warships. The tasks are:

(a) Strategic nuclear deterrence and support of the SSBN force.

(b) Defence of the UK Base. This requires seaward defence, mine countermeasures (MCM) forces and shallow water anti-submarine warfare (ASW) capability, and could involve defensive mining, shore-based ASW helicopters and surface ASW escorts with sonar and weapons appropriate to shallow water. Early warning of a threat to the UK Base demands good surveillance and intelligence gathering capabilities. Lastly, there are our offshore interests to safeguard.

(c) Operations under NATO command. These include:

(i) Defence of reinforcement and re-supply shipping, which needs capable, seaworthy, general purpose escorts able to deal with a wide variety of threats and able to protect unarmed vessels in company. Surface and submarine ASW barriers and other submarine operations also have their part to play.

(ii) ASW support for the US Strike Fleet, which requires the full range of modern maritime weaponry including submarines, Towed Array Frigates for ASW surveillance and helicopters for location and attack of hostile submarines. Anti-Surface Vessel (ASV) guided weapons and Anti-Air-Warfare (AAW) defence, auxiliaries for support and, of course, reliable electronic counter measures resistant command control and communications (C^3) inter operable with our NATO allies and with the USN in particular are also needed.

(iii) We have also to deploy and support the UK/Netherlands Amphibious Force, requiring a surface and helicopter borne amphibious lift capability together with appropriate escort and support forces and an ability to provide Naval gunfire support.

(d) The fourth range of operational tasks stems from operations under National Command. The main items are:

(i) Naval diplomacy in support of foreign policy. These tasks include a Naval presence to stabilise a deteriorating position, goodwill ship visits abroad and training of foreign naval personnel.

(ii) Defence of merchant shipping.

(iii) Amphibious intervention, including such operations as those in the Falklands or civilian evacuation.

(iv) Surveillance, which takes place in peace, tension and war and is an essential factor in the general pattern of operations designed to deter any potential aggressor from acting against UK or alliance interests at sea.

3.2 Major Fleet Assets

Before leaving this description of the Royal Navy's likely tasks under both National and NATO Command, I would like to add a word to show how platforms other than surface warships fit into the pattern of operations. Each has an essential part to play if the whole is to be successful.

3.2.1 Submarines

The Nuclear-powered fleet submarine (SSN) is our primary ASW platform. Its flexibility, endurance and capability to operate in a hostile surface and air environment give it attributes held by no other vehicle. SSNs may be employed on forward operations, ASW barriers, in support of a surface force such as the Strike Fleet and in ASV operations. The conventional diesel submarine despite its reduced mobility is also an effective ASW and ASV platform, not regarded as a cheap SSN but rather as a complementary platform for use in more limited patrols and in shallow water.

3.2.2 Organic Aircraft

Organic aircraft comprise the shipborne Sea Harriers and helicopters. The Sea Harrier has an essential part to play in keeping at arms length enemy surveillance aircraft and has a useful general air defence capability, especially relevant for operations outside the range of shore based aircraft. It can also be used for other roles such as anti-surface vessel attack.

3.2.3 Helicopters

Most modern Naval surface ships carry ASW helicopters which, according to their size and role, can be used for screening, weapon carrying and surface search and attack. A further role for the helicopter is the Commando lift and these helicopters can be carried in the Invincible class, Fleet Auxiliaries and the Assault ships (INTREPID and FEARLESS).

3.2.4 Land Based Aircraft

The Royal Air Force makes an important contribution—Nimrod maritime patrol aircraft are an essential element of the ASW battle and shore based attack aircraft might also have a significant part to play in the campaign at sea.

3.3 Flexibility

In the face of such a wide variety of possible tasks and in an uncertain future, robustness and flexibility are the watchwords. The value of optimising equipment by which NATO would counter the Warsaw Pact needs to be balanced against inventory versatility for a range of situations.

The next section of the paper reviews the capabilities required to conduct the specialised anti-submarine, anti-air and anti-surface ship warfare.

4. ANTI-SUBMARINE WARFARE

4.1 Concept

The basic concept of ASW operations has changed dramatically in recent years. In the early post war years the primary sensor (active sonar) had a short range; ASW weapons were also short range and the ship thus required considerable manoeuvrability and several knots speed advantage over the submarine in order to remain close to its quarry. Sonars produced beams which were angled down, and, as the ship approached the submarine, contact would be lost and this in conjunction with the time it took the depth charges to sink (dead time) gave the submarine a chance to evade. Sonar detection ranges were increased. These could not always be exploited, however, because of the distortion of the sonar beam by thermal layers in the sea which produce blind zones where the submarine can hide. Variable depth sonars were introduced to overcome this problem. Stand-off weapons enabled the extra sonar range to be exploited and eliminated the need for the speed advantage over the submarine but the time of flight still provided a dead time for evasive action. Homing torpedoes, either ship launched or missile carried, were an attempt to overcome this problem; missile carried nuclear depth charges capable of killing submarines at some distance were another but these, of course, have to be detonated at a safe distance from the attacking ship. Some long-range systems enabled the ASW ship to exercise control of the weapon in-flight and the ultimate form of control is the use of the manned helicopter. In order to provide the necessary availability, two aircraft are required with a hangar and good maintenance facilities. Practical considerations dictate that for frigate size ships, the flight deck must be at the after end, with the hangar forward of it. Helicopters do not have an all weather capability yet and it is usual to provide a secondary ASW weapon, such as ship launched torpedoes.

4.2 Hull factors

The hull form is influenced by the need to minimise ship motions both for helicopter operations and to avoid bringing the sonar domes out of the water. Noise levels at the sonar site are important and it is possible to mount them in the bow where they are least affected by ship-generated noise. But this has to be traded against the increased likelihood of emergence of the sonar dome and the need for very fine lines forward to give good flow over it.

4.3 Advent of towed arrays

During the 1960s, hunter killer submarines were introduced to reinforce ASW capability. More recently, large fixed sonar installations and long range patrol aircraft using sonobuoys have been used for ASW surveillance. The most dramatic improvement, as far as surface Warships are concerned, has been the development of very long passive towed arrays (TA) which give an order of magnitude increase in detection ranges compared with active sonars. This led to the requirement for the Type 23 and these requirements are discussed in somewhat more detail later.

4.4 ASW Operations

There are four distinct phases to ASW operations, detection, classification, location and destruction. Detection refers to the determination of the approximate bearing and range of the target, classification to type of target, location, the fire control solution; and destruction is self-explanatory.

TA sonars give the bearing of a target and its mirror image (about the TA) and this bearing ambiguity has to be resolved by changing course or using information from another TA Ship. This can also provide range information.

4.4.1 ASW platform quietness

In order to exploit the full potential of the towed array the platform must be designed and operated to minimise the ship's radiated noise level at the array, illustrated in Fig. 2. As the towing speed is increased, the flow noise around the array increases and eventually limits the performance of the array. Thus, up to this critical towing speed, the propeller should not cavitate.

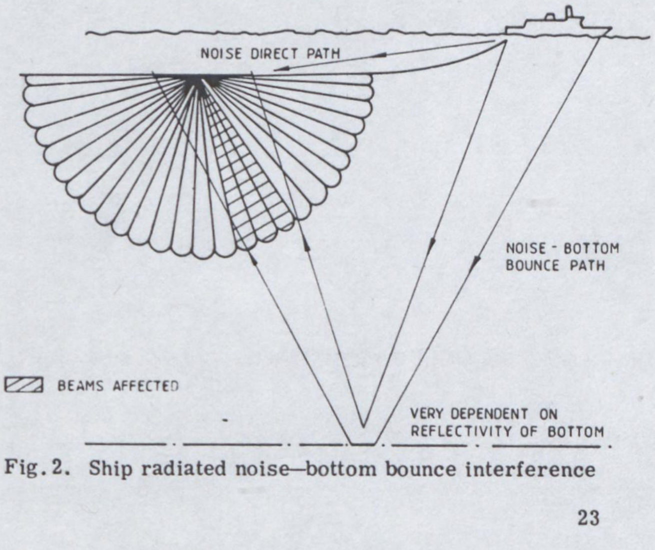

Fig. 2. Ship radiated noise—bottom bounce interference

4.4.2 Ship machinery noise

At speeds below the cavitation inception speed of the propeller, the ship's radiated noise is dominated by that generated by main and auxiliary machinery and thus the machinery must be selected against this criterion. Since the noise performance of machinery can deteriorate in-service without any obvious fault occurring, a method of monitoring radiated noise and giving some diagnostic capability is required. Furthermore, since it is impracticable to make significant improvements in ship radiated noise after build, the design noise target level must take account of probable improvements in TA performance during the ship's life. Reduced radiated noise levels make passive detection by the enemy much more difficult.

4.4.3 ASW platform speed and endurance

There is a balance to be struck between ship speed and detection range and this will depend on the environmental conditions. Classification of targets requires very low speeds and therefore the design of the machinery must be capable of prolonged periods at low speed (which requires relatively little power) and also the need for accurate course keeping at these speeds. A relatively high top speed is required for fast transit.

The TA ship should have sufficient endurance for the required number of days on task to avoid the need to replenish and the consequent noise interference from the RFA.

4.5 ASW helicopter ship requirements

After initial detection and classification, a helicopter carrying sono-buoys for localisation and torpedoes for prosecution is used. The helicopter may be called from another ship but the ability to operate helicopters from the TA ship significantly enhances the ship's capability. The availability of the aircraft will depend on the facilities provided. A flight deck with only refuelling and re-arming facilities limits the time the aircraft can be deployed with the ship to a few days. A garage hangar to protect the aircraft from the elements increases the number of days by a factor of three and the impact upon the ship design can be minimised by using such options as a collapsible hangar. A fixed hangar plus limited second line maintenance enables the period to be increased by a further factor of three making it compatible with the ship's endurance but by this stage the aviation facilities are a major influence in the ship design. In particular, some means of handling this large aircraft on the deck must be provided. The operational capability of the aircraft is enhanced by having a restraint system for landing and some system to move weapons safely to the aircraft. The demands on these systems become very large as the sea state increases, particularly since the ship must maintain a consistent heading with the array deployed.

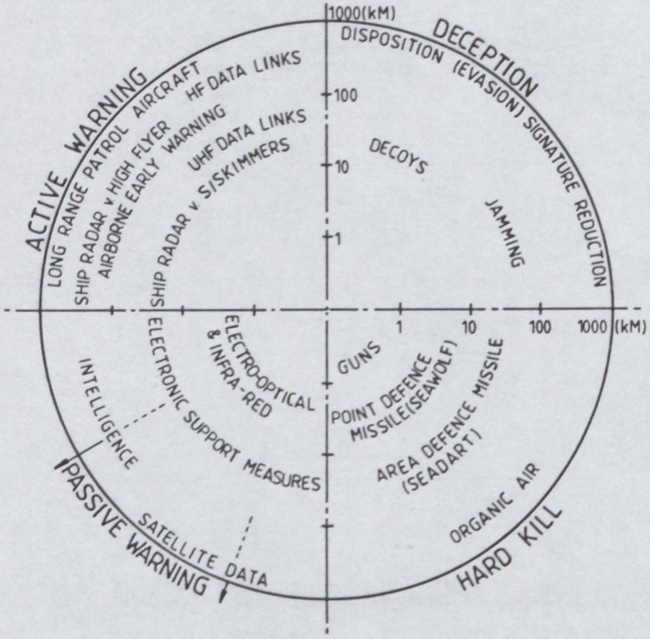

Fig. 3. This diagram illustrates the components of multi-layered surface ship anti air defence. Approximate ranges are indicated on a log scale

4.6 Shallow water ASW

The TA has limited capability in shallow water and to give flexibility of operation the inclusion of an active sonar has to be considered.

4.7 ASW Summary

Thus the ASW role imposes severe constraints upon the ship design: low radiated noise to enhance towed array detection ranges, good slow-speed characteristics and good seakeeping to permit helicopter operations in high sea-states without altering course. We must now examine the anti-air and anti-surface ship requirements and see how they can be provided in conjunction with good ASW performance in the same hull.

5. THE CAPABILITIES NEEDED TO CONDUCT ANTI-AIR AND ANTI-SHIP WARFARE

5.1 Anti-ship capability

Turning first to offensive anti-ship capability. The essential attribute is to hit hard and accurately at long range since, as has always been the case, risks to an attacker increase as distances close. Today, the sea-skimming guided missile, travelling at just subsonic speed, is the principal weapon. Targets can be identified in many ways and over the horizon targeting is a fast developing art. In locating the target, active techniques such as radar can result in the disclosure of ones own presence to the enemy, and passive methods are preferred. A sea-skimming attack reduces the time available for effective defensive action, and the sea-skimming missile achieves impact and destruction of the target by active terminal homing associated with kinetic penetration and a blast warhead. For ships of Frigate size, one such hit may be sufficient, but the probability of a successful engagement is enhanced by adoption of salvo launch. Accurate attack at long range can also be achieved by shipborne aircraft, both fixed and rotary wing. For small and lightly defended targets, the deployment of expensive guided weapons may be avoided by using guns. A range of calibres is available of which the 4·5 inch is currently the largest in service with the Royal Navy. Some offensive actions are still tailor-made for the gun. Shore bombardment in support of landings is a recent example from the Falklands war; the stopping or sinking of minor vessels another.

5.2 Anti-air Warfare

5.2.1 Anti-air self defence

Such defence is one of the most demanding requirements for today's surface ship. The advent of satellite surveillance and long-range patrol aircraft with specialised electronic sensors has removed most of the ability of ships to disappear into vast ocean areas and evade detection, as practised by surface raiders in past wars at sea. A surface ship's survival will depend on countering effectively stand-off missiles launched from aircraft, ships and submarines. To meet this threat, the philosophy of a layered defence for ships, illustrated at Fig. 3, has been evolved. This uses a mixture of aircraft, air defence missiles, specialised rapid-fire guns and/or close-in missile defence for hard kill or missile destruction and soft kill electronic countermeasures, designed to confuse the targeters or to deflect missiles from their targets. These measures together with reduction of one's own signature to make enemy sensor acquisition more difficult, are essential in the business of survival. The associated equipment requirements can be difficult to contain within a frigate hull.

Even with attention to all these areas, direct attack and overflight by aircraft reminiscent of the Second World War remains a possibility, as experienced recently in the Falklands. This illustrates the fact that the necessary acceptance of compromise is bound to expose ships to some degree of risk from all levels of attack even the most elementary.

In summary then, the surface weapon capabilities for ships may be seen to be a delicate compromise between desirable fire power, attack range and essential defence, set against the other needs of the vessel.

5.2.2 Future trends in anti-air self defence

What of future trends? There is little doubt that the surface threat to ships will increase as attacking-missile target-discrimination ability increases and counter-counter-measures and sensor performance are enhanced. The problem of saturation attack levels will continue to exercise defensive planning and equipment design, bearing in mind that, generally, only one missile hit is required to incapacitate a frigate-sized ship. But other technology changes could swing the odds more towards defence: weapons such as Vertically Launched Sea Wolf, guided projectiles and ever cleverer ECM hold much promise. Directed energy weapons may come, but not yet; the problems of beam distortion and path loss at sea level will need to be resolved before successful application is likely. For the nearer term, accuracy improvements resulting from the use of lasers for target designation and tracking, with beam-riding ordnance, appear more likely. The land application of 'smart shell' techniques is already under investigation for use at sea, with the promise of greatly reducing errors at longer ranges and perhaps marking some revival of the gunners' world. Whatever the future reality, one aspect is certain. Surface-ship survival will continue to depend upon the excellence of defensive systems.

Having looked briefly at the capabilities required to conduct operations against submarines and surface vessels and those required for self-defence, I now turn to the procedures we use to ensure that our ships are provided with the desired capabilities.

6. THE PROCEDURES USED TO TRANSLATE THE INITIAL REQUIREMENTS INTO AN OPERATIONAL WARSHIP

With the roles of the Royal Navy within Britain's maritime strategy defined and the capabilities desired described, the Navy has to determine how best to carry out its allocated tasks within the constraints of the defence budget.

This paper is not concerned with the nature of the longer term planning which is carried out into the future shape and balance of the fleet but with the development process applied to a particular warship to meet the operational requirements, capabilities and in-service date within any resource constraints. This involves a step by step progression from the original aim to provide a desired capability, through the initial evaluation of the aim, progressive formulation of a material solution and finally the placing of contracts and procurement of the warships or weapon systems. At all stages of this process, which is described in more detail below, we must assure ourselves that the options have been fully studied and the most cost effective solutions chosen. This is done using a well-defined procedure of consultation and approval.

6.1 Requirements

6.1.1 Initiation of New Requirements

New requirements for ships and weapons may arise for a variety of reasons either separately or in combination. These include a newly perceived threat, a change in concept of operations, a need to replace obsolescent equipment or a desire to make use of developments in technology brought about by research in MOD and industry.

6.1.2 Definition of requirements

The way in which the requirements are defined and developed varies slightly from project to project and more substantially as between weapons and warships. This is due to the technical development involved in a weapon and the fact that a warship involves the integration of a number of weapon systems into a whole fighting system and, of course, there are no prototype warships. Only one Staff Target/Requirement is raised for a ship and this covers all aspects of the design, i.e., hull, machinery, the arrangements for fitting particular weapon systems intended for the ship etc. However, individual sensor, weapon and communications systems have traditionally been subject to a separate Staff Target/Requirement mainly because each system is usually fitted into more than one class of warship.

6.2. Procurement procedures

The procedure described below and illustrated in the figures is a general framework within which the procedures for each individual project are formed. Its application to the Type 23 will be described later. Formal submissions are always required but the work involved in the preparation may vary. Besides providing assurance that expenditure has been fully justified, these formal procedures ensure that there is full consultation of all those with a possible contribution to make and that the particular project is considered in the national context rather than from a single Service view point.

As will be seen from Figs. 4 and 5 there is not a clear cut off between the various phases of projects. This is due to the variation in speed with which various tasks are carried out and the need to keep the team working whilst the formal submissions are being made.

The procedures for formulating the requirement for a warship will be described first. It should be noted, however, that weapon development usually leads ship design by some years as illustrated in Fig. 6.

6.3 Concept Studies

Free ranging concept studies are carried out in support of the Naval Staff long term view of the future shape and balance of the fleet, looking broadly at ship costs and capabilities. In this way, a knowledge of possible trade-offs between cost and capability and the military value of new ship concepts is developed. These studies can be initiated by the Naval Staff or from within the Sea Systems Controllerate and can last for anything from a couple of weeks to a year depending on the level of detail to be considered.

Major studies will involve inputs from Naval Staff, research establishments, weapon projects, manning and support departments, operational analysis staff and ship designers. Various options will be studied ranging from the cheapest and least capable to the option giving all the capabilities that might be desired. Unconventional solutions such as SWATH, hydrofoils and hovercraft will be considered and compared both in initial procurement cost and through life cost, with the more conventional solutions. The effects of various trade-offs in capability on cost and military effectiveness will be examined.

The shorter studies will concentrate on the costing of various options of weapon fit and ship capability e.g., speed, to determine what can be afforded and what is worth having. Again, the various trade-offs will be considered.

6.3.1 Fleet Requirements Committee

With the background of these concept studies, the Naval Staff formulate proposals for the future composition of the fleet and the broad material characteristics and capabilities of the ships to be included in that fleet. These proposals

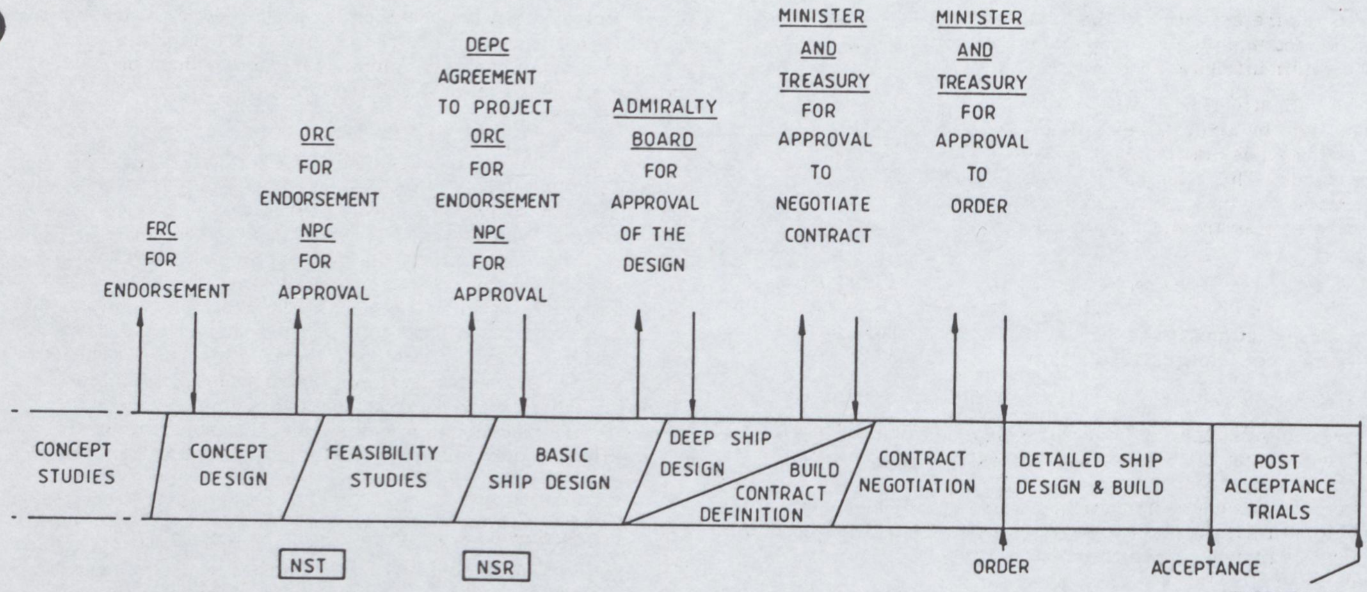

Fig. 4. Procurement phases of a first of class warship

are presented to the Fleet Requirements Committee (FRC) which provides guidance on the way ahead and sets the parameters for studies. The timing of the consultation with the FRC varies, depending on the complexity and importance of the project and the possible need for further guidance in the light of the results of studies.

6.4 Concept Design

With the FRC's guidance and instruction, a Concept Design is started. This will involve similar investigations to those included in the major concept studies described above and can be fairly described as the start of a new ship design project. The aim will be to firm up on one or two preferred options upon which to base a Naval Staff Target (NST). This phase will normally last between 6 and 12 months.

Since the development of major new ship systems and equipments may be a long process, it is often necessary to make quite detailed decisions at this early stage if systems and equipments already in production or development are not suitable.

6.4.1 Industrial participation in concept design

Industry will have been involved from the earliest stages by contracts for analysis work and outline system design. Besides individual work on equipments, systems analysis and assessment, the prospective shipbuilder will be con-

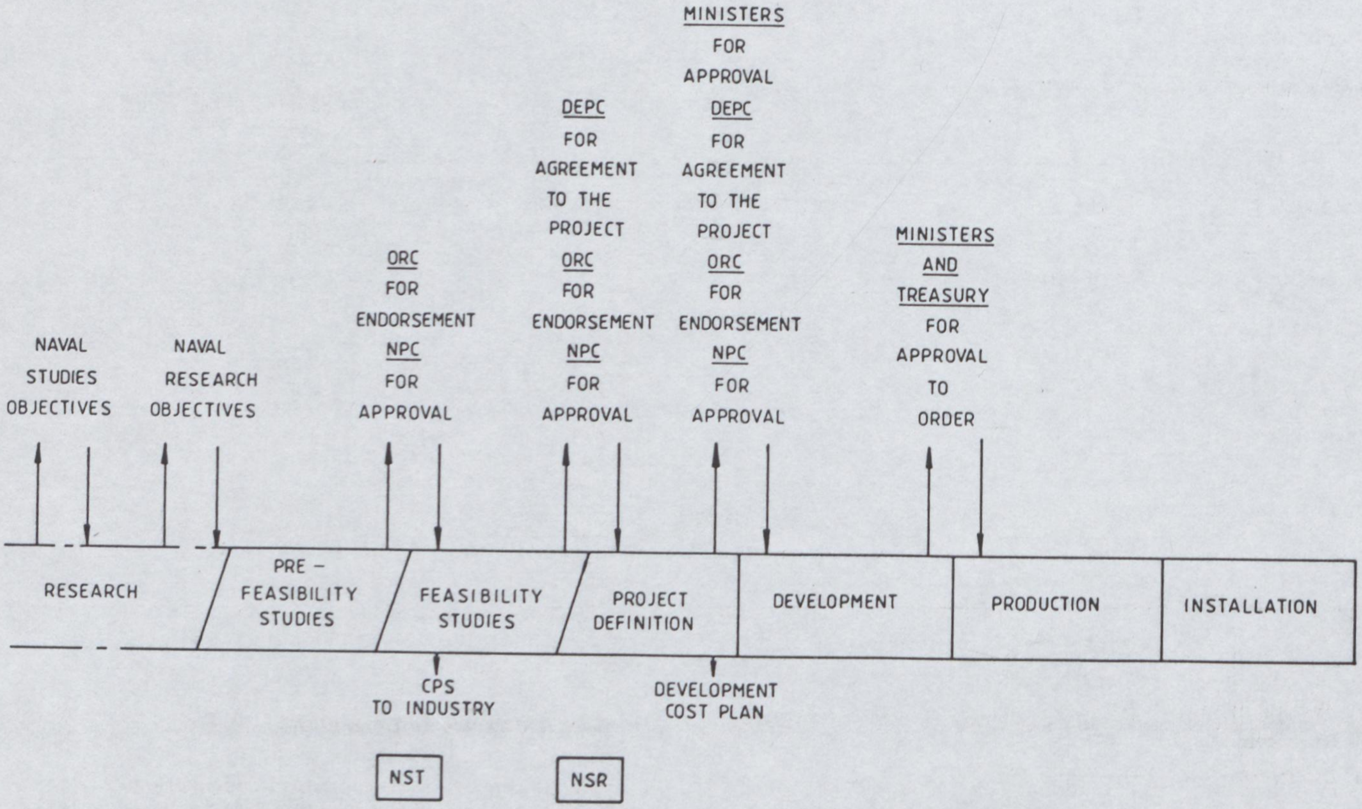

Fig. 5. Procurement phases of a new weapon system

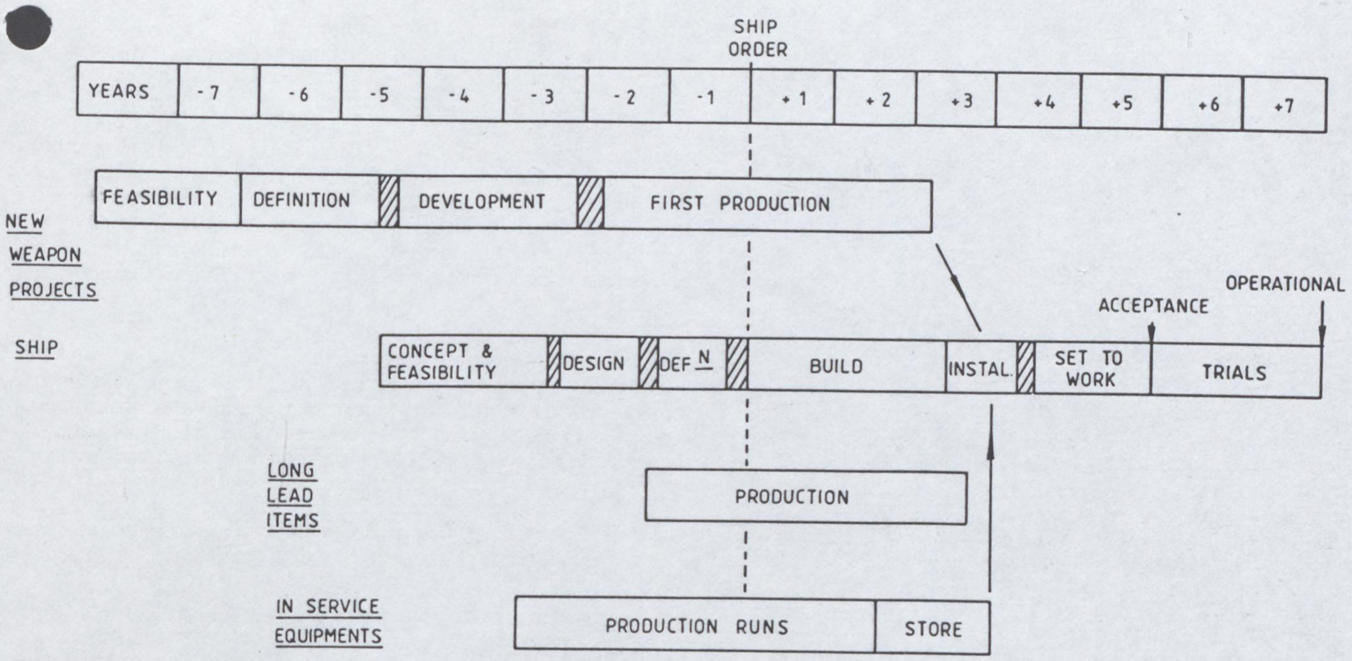

Fig. 6. Illustrates the relative phasing of ship design with procurement of weapons and fitting of equipment including long lead items such as gear boxes

sulted about the design options—in particular cost, production and overseas sales.

6.5 Naval Staff Target

In parallel with the concept design studies, the Naval Staff will be writing the NST. This is a brief statement expressing in broad terms the functions and desired characteristics of the ship before feasibility or other implications have been fully assessed, and will be accompanied by a supporting paper defining the place of the ship within the concepts of Fleet operation.

6.5.1 Naval Projects and Operational Requirements Committees

Once the papers have been produced, they are presented firstly to the Naval Projects Committee (NPC) and then the Operational Requirements Committee (ORC). The NPC under the author's chairmanship reviews the proposals both in relation to the available resources of finance and manpower and the overall naval programme but also examines the proposed procurement strategy. On behalf of the Admiralty Board, it approves the NST and recommends the ORC to endorse it. The ORC is a Central Staff Committee which scrutinizes all major projects to ensure that the NST is in line with current defence policy, that the project has a genuine place in the national armoury and that the allocation of resources is economical.

6.6 Feasibility Studies

With the ORC's endorsement obtained, feasibility studies begin. Their purpose is to establish that there are no major technical, cost or programme factors that might prevent the satisfactory development of the design and the construction and operation of the ship. Those factors of the design requiring early definition in order to meet the programme are identified.

6.6.1 Cost versus Capability

During this stage in the design process, the options produced during the concept design phase and identified in the NST are developed in greater depth. Estimates of cost and timescale are improved and further trade-offs between operational capability and cost are carried out with intense consultation between the Naval Staff and the designer, in order to achieve the best overall value for money.

6.6.2 Basic ship design phase

Design work is progressed to a level whereby budget allocations of cost, weight, space, power, chilled water etc. for each system are sufficiently well established to progress to the Basic Ship Design Phase on a sound basis. The nominated lead shipbuilder will have become closely involved in the development of the various system designs in order that he will be in a position to take on the responsibility for the detailed design.

6.6.3 Naval Staff Requirement

The work of the feasibility studies in design and analysis of capabilities permits the writing of the Naval Staff Requirement (NSR). This is an amplified version of the NST in which firm aims are stated in numerate terms and the operating environment defined. A supporting paper gives further details of the operational concept, manpower, cost and programme implications together with export potential and comments on the inter-relation with other ships and equipments and the through life support aspects.

6.6.4 Defence Equipment Policy Committee

The NSR follows the same drafting procedures as the NST, allowing full consultation within the shortest possible timescale. Submissions for endorsement of the requirement again go to the NPC for naval approval and to the ORC for overall defence consideration. However, since at this stage some significant degree of expenditure will be involved in the following design stages, submission is also made to the Defence Equipment Policy Committee (DEPC) which advises ministers whether the project should be included in the programme to meet the requirement endorsed by the ORC. Full account is taken by the DEPC of the defence budget resources, national industrial interests (including export sales) collaborative prospects and the possibilities of direct foreign purchase.

6.7 Ship Design and Procurement Phase

With the approval and endorsement of the NPC, ORC and DEPC, Ministers and the Treasury, the ship design is refined to meet the requirement as stated in the NSR. At this stage, the lead shipbuilder will become heavily involved and will take on responsibility as delegated design authority. The role of the MOD Project design team now becomes one of monitoring design development and ensuring that all experience with the existing fleet is fed back into the design. Further submissions to the committees are only required if the endorsed costs or programme require significant changes in the light of development.

The design is submitted to the Admiralty Board for approval of the technical features and, once sufficient details are available to define a contract, approval is sought from the Treasury and Minister to negotiate a contract, normally with the lead shipbuilder for the First of Class. The final contract is also subject to Treasury and Ministerial approval prior to order.

6.8 Small Warship Procurement

The above procedure is the basic framework for the more complicated major warships such as frigates and larger vessels. The exact way in which this has been worked for the Type 23 will be described below but for the smaller and/or simpler vessels, different procedures may be employed. Rawson(7) has described the Design and Build procedure whereby almost all the design work is done by the shipbuilder and it is around these two frameworks that a plan for a particular project will be formed. However, whatever the process adopted, full submissions must be made to the committees, Treasury and Ministers to ensure that the overall defence need is best served and resources are carefully used. Whilst it may not be necessary to write an NST, the initial concept will require endorsement by the FRC and all the other submissions will be the same as for a major warship.

6.9 Weapons Procedures

Whilst weapon systems are required to go through the same formal submissions as a warship, the way in which the Staff Target/Requirement is developed is different. However, as this is a paper about warships, I do not intend to treat it in any detail. Fig. 5 is illustrative of the process. Fig. 6 shows how weapon development and production programmes may have to be carefully dove-tailed in to the build of a first of class warship: playing it 'safe' could lead to a new ship having obsolescent weapons.

Having briefly described today's procedures, and before describing how the Type 23 evolved, it is worth taking a look at some past designs since the Second World War and appreciating why they took the shape they did.

7. MAJOR SURFACE SHIP DESIGN SINCE WWII

7.1 Special considerations

There has been a major shift in emphasis since the Second World War from requiring high calm water speed to the ability to maintain high speed in rough weather. High speed is expensive and in today's circumstances the top speed requirements must be subjected to particularly critical examination. Good seakeeping is probably more important and makes good sense since Sea State 5 and above occurs more than 60% of the year in the North Atlantic.

7.2 Leander Class

In the early 1950s, there were no computer models and hull forms were developed by experience and model experiments. A whole family of successful designs(2) was developed leading to the General Purpose (GP) Leander Class frigate, one of the most successful warships of all times. Considerable flexibility was built into the design by having a long upper deck length and a relatively short superstructure, allowing a wide variety of weapons to be fitted. Flexibility was incorporated internally by having 'soft' accommodation areas adjacent to operational spaces and radio and radar offices. It is of great credit to the designers of yesteryear to note that the Leander Class has been successfully modernised with a variety of major new weapon systems such as the big 2016 long range sonar, Sea Wolf, Ikara and Exocet.

7.3 Whitby and Blackwood Classes

During this period, there were two notable second rate Frigate designs. At £3½M (about £30 million at today's prices) the Whitby Class were considered to be unduly expensive and it was decided to design a smaller and slower second rate Anti-Submarine Frigate, the Type 14 or Blackwood Class. The ships were relatively long and lean to achieve the speed on half the power of the Whitby Class driving into a single shaft; they had a good freeboard and a short bulwark for seaworthiness. The restriction of functions and pruning of the requirement to the minimum reduced the cost to half that of the Whitby. Table II illustrates the main dimensions and capabilities of the two classes.

Technically, they were a success though never popular with the Navy as their strict limitation to a single role made them inflexible in deployment and the 'second rate' is never very popular. Their good seakeeping was used to advantage for fishery protection duties in Northern waters.

7.4 The Tribal Class (Type 81) Frigate

The Type 81 Frigate introduced in the mid-fifties reversed the policy of specialised frigates and had limited capabilities in the ASW and AAW roles. The requirement called for a minimum speed of 22 knots with 25 knots desirable and an endurance of 5000 nm at 12 knots. Somewhat more power than was necessary to meet the ahead speed requirement was installed to ensure adequate astern power and a 12,500 shp steam plant combining with a 7,500 shp G6 gas turbine (GT) was selected, driving through a single shaft to reduce cost. It was the first operational warship to have GT propulsion. The hull form was optimised for good endurance at 18 knots.

The Type 81s were relatively expensive and the technology was changing so fast that they were verging on obsolescence as they came into service. The secondary task they could perform could be carried out quite adequately by obsolescent first rate ships.

7.5 CVA 01

A design which never got off the drawing board was CVA 01. It was to have two roles, firstly to hit the enemy on his airfield and, as its secondary role, to shoot down attacking aircraft; in other words, she was to be a strike carrier. A somewhat unrealistic limit of 50,000 tons was placed on

TABLE II. Comparison of Whitby and Type 14 Frigate Classes

	Whitby	Type 14
Length Overall (m)	112·8	94·5
Length on Waterline (m)	109·7	91·8
Beam (m)	12·5	10·1
Depth (m)	8·8	8·5
Draught (m)	4·1	3·5
Displacement (tonnes)	2,540	1,650
Machinery Type	Steam	Steam
Shafts	2	1
Power (MW)	22·5	11·2
Speed (knots)	28	25
Accommodation	260	144
Armament	1 × Twin 4·5 1 × 40mm 2 × A/S Mortar	3 × 40mm 2 × A/S Mortar
Sonars	170, 177	As Whitby

e ship designers in the mistaken belief that cost is proportional to displacement. The minimum length of the catapult is determined by the limits of acceleration of the human frame (about 4g). With space for crash barriers and arrester gear a minimum flight deck length of about 1000 feet is required, leading to a displacement of 60,000 tons or more. Many novel features were necessary to keep the displacement below 50,000 tons but novelty tends to drive the cost up. In the event, it became apparent that the overall demand on the Navy's resources would be greater than the Navy could afford and the project was cancelled.

7.6 The Type 82 Guided missile destroyer

The Type 82 (Fig. 7) stemmed from an original concept in 1962 for an improved Leander Class Frigate based on the next generation guided missile systems. It was the first attempt at modular construction and was very ambitious with prototype equipments in all military spheres—Sea Dart, Ikara, Anglo/Dutch Radar (subsequently cancelled), 4·5 inch Mk 8 Gun Mounting—and the Olympus Gas Turbine. The cancellation of CVA 01 threw doubt on the need for a ship of this type and in view of the escalation in size and cost, it was decided to complete the first ship as a weapons trials ship and no more.

7.7 The Type 42 destroyer

The Type 42 was designed primarily to deploy Sea Dart for area air defence with secondary roles of hunting and destroying submarines and surface ships, shore bombardment, peacetime police and patrol duties. There was an understandable desire to produce a substantially smaller and cheaper ship than the Type 82. Length was thought to be a big factor determining UPC and thus length was constrained to the minimum. The incorporation of a Lynx Helicopter and hangars meant that the Sea Dart had to be sited forward. Constraints imposed by the magazine in conjunction with the short length led to the seakeeping being somewhat poorer than Leander Class. In order to keep the cost down to what the Navy could afford, it was necessary to accept design standards based on Leander Class (except for main machinery) and, more importantly, the Admiralty Board accepted that there would be no margins for further modernisation.

The cancellation of the Anglo Dutch 3D radar due to cost escalation and technical problems meant that the almost obsolescent 965 radar had to be used and its performance was incompatible with the performance of Sea Dart. It has been a weakness of some NSRs that the required capability in each of the functions is not fully defined. Later ships have improved radar and the last few have been increased in length to give some flexibility for future updating. This increase in length has restored the seakeeping characteristics to what they should have been. It is worth noting that the lengthier Type 42 at an additional 300 tonnes goes approximately 1½ knots faster.

7.8 The Type 22 frigate

The building of Leander Class frigates lasted throughout the 1960s. Discussion on the follow-on class continued for some years as the search for the correct solution was pursued.

In 1968-69, the true Leander replacement began to take shape as the Type 22 class. Its main features were to be good seakeeping qualities combined with a balanced offensive/defensive capability compatible with its general purpose role, i.e., to have a much improved weapon capability. The aim was to be a ship more capable than the Leander and with a smaller complement. The aim was achieved. Also, significantly improved accommodation standards were introduced into the Type 22, requiring some 4% more of the internal volume of the ship by comparison with a Leander.

The design was, at the outset, a collaborative project with the Dutch and they imposed a maximum length to enable them to use an existing dock. The main machinery selected was the Type 42 COGOG plant but some improvements in layout were achieved. Subsequently, the Dutch withdrew, and the design was lengthened to increase the space available for the enhanced weapon fit. Late increases in aviation facilities to accommodate two Lynx helicopters were accomplished by a rearrangement of the after part of the ship but with some top weight penalty.

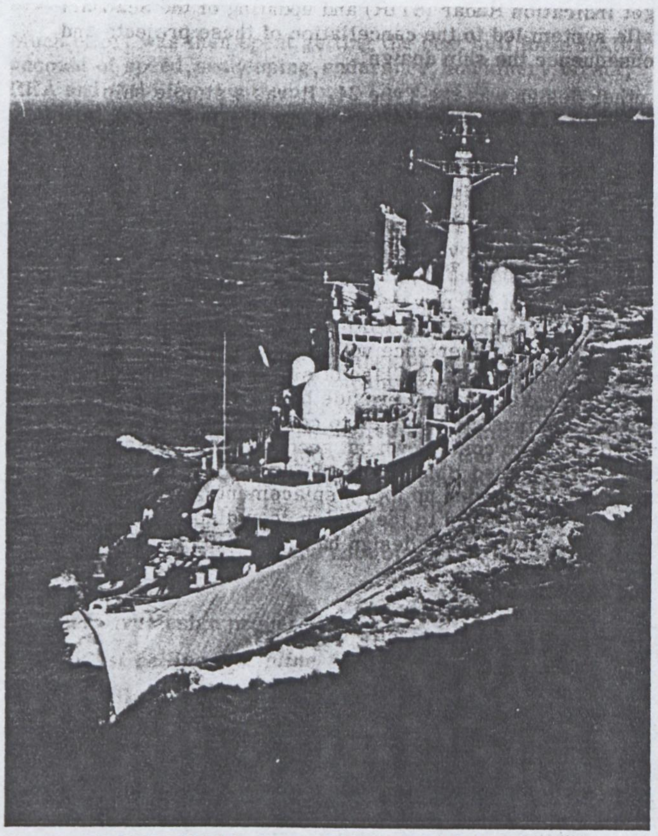

Fig. 7. HMS BRISTOL—Type 82 guided missile destroyer

7.9 The Invincible Class

The evolution of the Invincible Class(3), a helicopter carrier, which was to be the nucleus of the anti-submarine task forces, took rather a long time. The roles were initially command and control, anti-submarine warfare, defence against aircraft and missiles, but with organic air defence (VSTOL) added later. The main factors controlling the design were hangar size, Sea Dart Launcher arrangements and gas turbine machinery. The possibility of using VSTOL aircraft was the subject of a lengthy debate before approval was given. VSTOL aircraft can be carried in lieu of helicopters on a 1 for 1 basis but this does not take into account the very much greater variety of munitions and more extensive support requirements of VSTOL aircraft and the impact of these requirements is considerable. There is much ill-informed comment about the ability to land VSTOL aircraft on small platforms but without adequate support facilities there can be no effective operation. The capability of the VSTOL aircraft has been significantly enhanced by the addition of the VSTOL ramp.

7.10 Paper exercises

There were two more major designs which were developed during the late 1970s and which did not get off the drawing board. The first was the Type 43 which was to be an area air defence ship with Sea Dart, Sea Wolf and Exocet Missiles, 4·5 inch Mk 8 gun, an EH101 helicopter and a top speed of about 30 knots. The cost grew to unacceptably high levels and a more compact design, relabelled Type 44, developed. However, the cost of development of the Surveillance and

Target Indication Radar (STIR) and updating of the Sea Dart missile system led to the cancellation of these projects and in consequence the ship design.

The other design was the Type 24. It was a simple ship which could act as a towed array sonar ship and would be adaptable for export potential. The design was handed over to British Shipbuilders to develop but, after many changes, was not found attractive to either the Royal Navy or the export market.

7.11 Offshore patrol vessels

The emergence of the new requirement on the Navy to provide offshore protection led to the rapid introduction of the Island Class. Experience with these ships led to the development of the Castle Class of slightly longer length to improve seakeeping and provide higher speed(4). Emphasis continued to be given to commercial type standards to keep costs down but good margins of stability and strength enabled HMS DUMBARTON CASTLE to sail to the Falklands loaded up to a displacement of over 2,000 tonnes compared to the design deep displacement of 1,450 tonnes. This basic design has the ability to take many different weapon fits.

8. THE EVOLUTION OF THE TYPE 23

8.1 The Basic Configuration

8.1.1 Outline requirement

The scene was now set for the emergence of the Type 23 (Fig. 8). An Outline Staff Target emerged in the Spring of 1981 from concept studies into a light ASW frigate. The essential features were a quiet platform to maximise the effectiveness of the current and projected towed array, high endurance at the moderate towing speeds, a flight deck for a medium helicopter (EH101) with the ability to refuel and rearm the aircraft, hull and superstructure configured to minimise radar echoing area (REA) and, perhaps most importantly, the unit production cost (UPC) was fixed at a maximum of £70M at September 1980 prices. A typical breakdown of this UPC is shown in Fig. 9.

8.1.2 Complement

Men have a significant impact on the size and cost of a ship and the Type 23 was to have a substantially smaller complement than a normal frigate of the same size. To achieve this, the mission time was reduced and on-board maintenance limited to defect rectification. This latter change represents a substantial departure from the traditional way ships of the Royal Navy have been supported.

8.1.3 Choice of Propeller

In developing the design, the aim was to raise the cavitation inception speed (CIS) above the maximum surveillance speed of the towed array determined by flow noise over the array. Even though cost constraint was paramount, it was evident that a twin shaft arrangement was preferred incorporating the maximum diameter, slowest rpm propeller, practicable. There were three possible options for the propulsor namely a fixed pitch propeller (FPP), a controllable pitch propeller (CPP) or a pump jet. For the same diameter, the blade loading of an FPP can be reduced below that of a CPP and therefore the noise performance is better. The pump jet can provide further noise reduction but at considerable extra cost. Studies showed that it was possible to meet the required CIS with an FPP and this was the preferred option if the selected machinery could turn the propeller in both directions to provide ahead and astern power.

8.1.4 Propulsion

There were several key factors determining the selection of the main machinery, namely low rpm, ability to operate for long periods at low speed (and hence low power), low noise and an ability to provide astern power with FPP. Fig. 10 shows a comparison of underwater noise for various machinery configurations. The noise level from the diesel electric propulsion system gave it the best potential of the installations considered (taking into account future requirements of the TA) and the electric motor is capable of driving in both directions, so it was possible to use FPP. However,

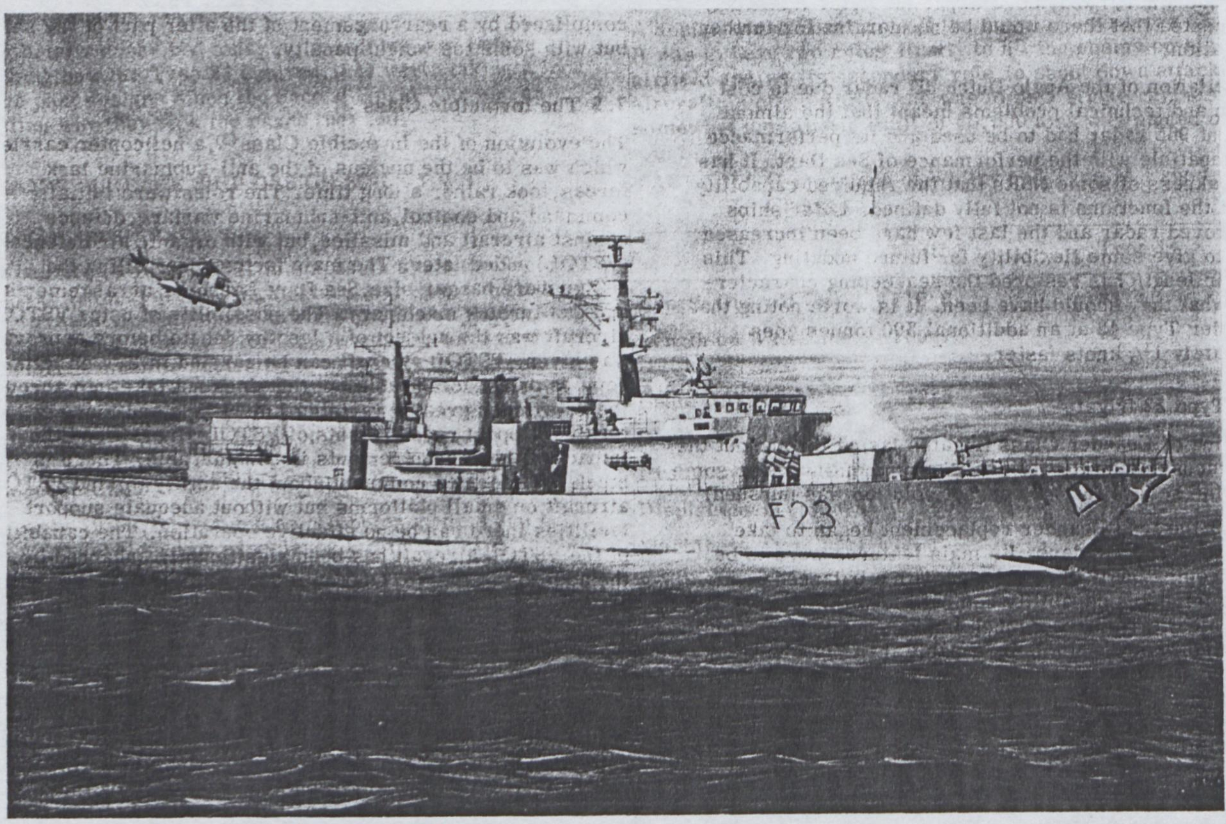

Fig. 8. An artist's impression of the Type 23 frigate

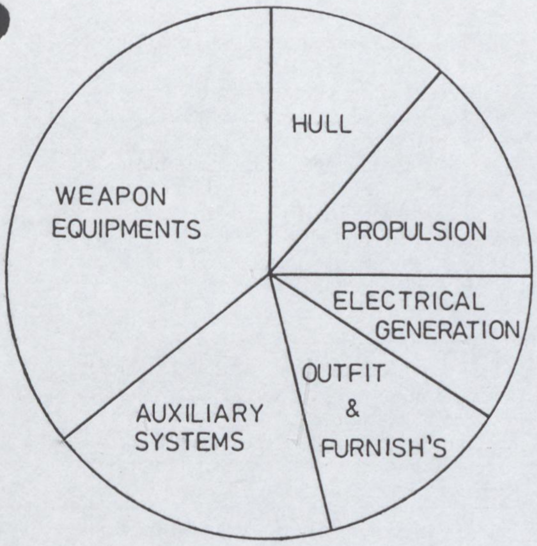

Fig. 9. Typical cost breakdown

in view of the limited astern power, computer simulations were carried out of the crash stop capability from full ahead. These showed that whilst this machinery would not match the COGOG ship stopping distances, it would be similar to Leander Class frigates.

It should be noted that part of the improved noise performance with diesel electric fit shown in Fig. 10 is due to the elimination of gearbox tonals by mounting the electric motor directly to the shaft.

8.1.5 Siting of generators

Having established the advantages of diesel electric propulsion, some of the additional costs of noise reduction measures to the diesel generators (raft mounting with acoustic hoods) could be minimised by siting them as far above the waterline as practicable. Early arrangements had all four diesel generators on No 1 deck but subsequent pressure for upper deck space meant that only two were sited on No 1 Deck. A further way of off-setting the additional cost of diesel electric propulsion was achieved by integrating ship and propulsion electrical supply systems.

8.1.6 Noise reduction

In addition to the main machinery, noise reduction measures have to be applied to all machinery running in the quiet state and submarine experience has given a good indication of what is required.

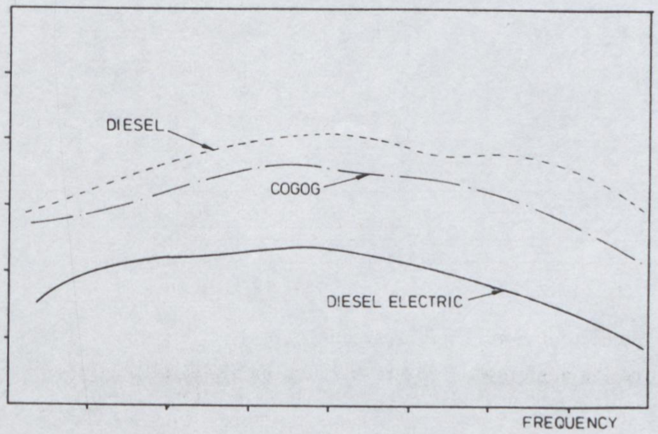

Fig. 10. Comparison of underwater noise levels attributable to propulsion machinery

8.1.7 Hull form

Much effort was then spent getting the best hull form taking account of speed, seakeeping, endurance, machinery layout, REA and stability requirements. The CASD(6) programs enabled this to be done very thoroughly (Fig. 11).

8.2 Design Management

Having established the basic configuration of the ship, a number of study groups was set up to investigate such aspects as ASW effectiveness, manning levels, support policy, Command, Control and Communication requirements, aviation requirements and vulnerability.

The MOD in-house design team explored a wide range of options taking account of the findings of the study groups to identify the best balance of capabilities to meet the cost remit. At the same time, Yarrow Shipbuilders Limited (YSL) and Vosper Thornycroft were invited to submit designs which met the basic TA requirements and had export potential. There was a good measure of agreement between the three design teams that the basic size and displacement to meet the cost target was about 100 metres and 2,500 tonnes and that noise standards were not going to be achieved cheaply.

8.3 Iterative design process

8.3.1 Cost ceiling discipline

During 1981, there were numerous drafts of the NST with the Naval Staff struggling valiantly to produce a balanced set of requirements which had some prospect of remaining within the cost ceiling. The NST presented to the committees at the end of 1981 a minimum package which retained a fairly high top speed and some GP capability to give the ship export potential, inevitably at the expense of the other important ASW features, and the required length was about 107 metres. The Aviation studies had shown that, without some protection from the elements, a helicopter on the Type 23 would become unserviceable after a few days; the vulnerability assessment had shown the value of some form of self-defence. In developing the design, in order to reduce the cost, a reduction in top speed had been accepted by the Naval Staff. One SPEY Engine was removed and a contract was placed with YSL for machinery feasibility studies on a single SPEY sided boost arrangement. A contract was also placed on YSL to investigate ways of reducing cost. One major innovation has been the use of transversely framed structures in some areas to reduce cost but with an increase in displacement of some 40 tonnes. The Committees endorsed the NST but commented that the design should be optimised for RN ASW operations, the fitting of some point defence missile system (PDMS) was desirable and at least a garage hangar should be provided. These recommendations would take the cost somewhat above £70M but would give a substantial improvement in weapon effectiveness.

8.3.2 Improved self-defence and aviation facilities

The design was quickly reconfigured on a length of 115m incorporating a single headed Sea Wolf (one tracker and

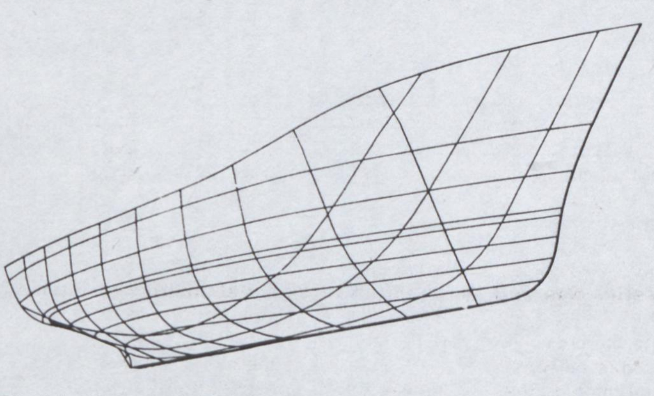

Fig. 11. Computer developed hull form

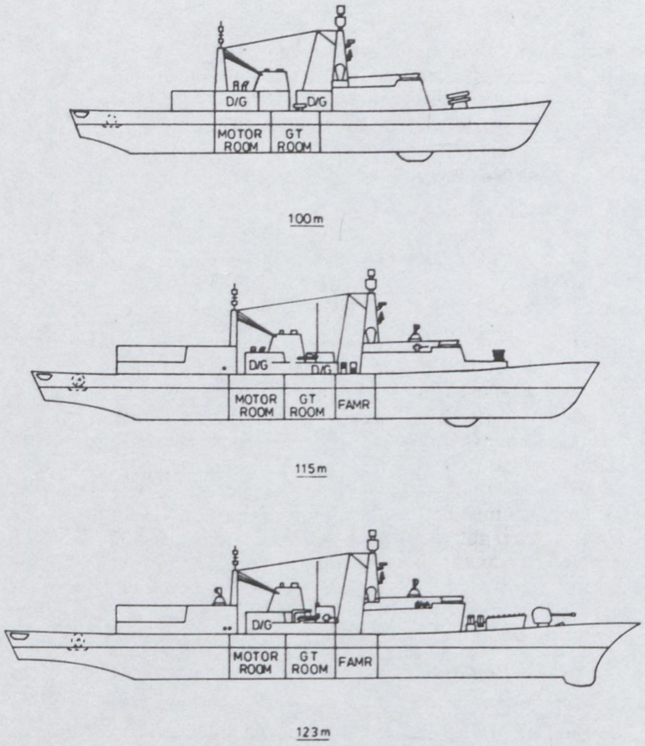

Fig. 12. Evolution of the Type 23

one launcher) system and a hangar with limited second line maintenance. Studies were put in hand to develop a suitable aircraft and weapon handling system to ensure that the full capability of the aircraft could be exploited. Parallel studies were carried out with other weapon systems such as close in weapon systems (CIWS) to explore cost differences. The NSR was developed with these changes and submitted to the Central Committees for endorsement in the early part of 1982. The Committees then added back the second SPEY and also added a second Sea Wolf tracker to provide all-round cover. A requirement to be able to land the Sea King as well as operate the EH101 was also introduced at this time and added a further 3 metres to the length.

8.3.3 Exploitation of increased length

The design was again rapidly reconfigured on a length of 118m and the additional length was used to reduce congestion in the machinery spaces and to make a small increase in accommodation areas. These increases in length and changes in configuration during the design process are illustrated in Fig. 12.

8.3.4 Ship design contracts

An order was placed with YSL in mid-1982 to proceed with the Type 23 ship design. A contract was also placed with YARD for a parallel ship design study to ensure that the best balance of capabilities had been achieved.

8.4 Falklands War impact on design

By the end of 1982, we had analysed the experience gained in the Falklands and it was evident that some changes to the design should be considered. The most important lesson was that much greater emphasis should be placed on the containment of smoke and fire in addition to the traditional containment of flooding; and, in particular, ventilation trunking design in the Type 42s proved to be a major weakness. It should be remembered that the threat posed by sea skimming missiles was well known in the 1980s but almost non-existent in the 1960s when the Type 42 design was completed. The Type 23 had been divided into three sections by two fire containment bulkheads. Ventilation trunking did not cross these boundaries. It was decided to increase the fire containment bulkheads to four giving five sections. This, in fact, required negligible change to the design since the ventilation system had been grouped as far as practicable between main transverse bulkheads. In order to reduce cost, it had been the practice to allow openings in the bulkheads below No 1 deck to simplify the running of cables. This practice has been discontinued in order to provide additional containment of blast, smoke and fire. The whole philosophy and extent of the damage control and surveillance system has been reviewed to align with the five sections. Particular consideration has been given to avoiding the need for personnel to cross these zone boundaries and to the provision of good escape routes in each section.

The runs of the key systems (HP Salt Water, Electrical Distribution, Chilled Water, Air) have been reviewed and modified as necessary to increase their ability to cope with action damage. In particular, two diesel driven HP salt water pumps and an emergency diesel generator have been provided. The distribution and isolation of these systems have been made consistent with the five sections referred to in the previous paragraph. Splinter protection has been provided for some high value compartments.

8.4.1 Combustible materials

Improvements in habitability standards in the 60s and 70s led to an increase in the use of combustible materials and, in some cases, materials producing toxic fumes. Linings had been extensively fitted and these hinder damage control. It has been the policy in the Type 23 to minimise these features and the Type 23 design will be considerably more austere than the Type 22.

8.4.2 Siting of mess decks

Another notable change has been the re-siting of mess decks as high in the ship as possible to speed up the movement of personnel when going to high action states.

8.4.3 Type 23 stretch potential

The foregoing paragraphs indicate that at every stage of the development of the design only the minimum essential facilities were included but, as part of the post-Falklands review, there was a deliberate policy to provide some flexibility for the future and this, together with the changes described above, required the length to be increased to 123m, the maximum length that could be accommodated in the Frigate complex at Devonport. A large number of other smaller additions were made to the design to improve the ability of the ship to withstand damage.

8.4.4 Gunnery

There was also a number of changes to the capabilities of the weapon systems, the most notable being the inclusion of a medium calibre gun for shore bombardment.

8.5 Design approval

In view of the extent of the changes, the design was re-submitted to the various outside bodies involved to ensure their requirements had been met.

It was decided that the changes and the cost increase in relation to the original cost remit required the design to be resubmitted to the Committees. Ministerial approval was given for the design to proceed with the Falklands changes and the formal responsibility for the general arrangement was passed to YSL. The detailed design proceeded rapidly and the design was submitted for Admiralty Board approval in the middle of 1983, when the decision was taken to make Vertical Launch Sea Wolf the point defence system and the 4·5 inch Mk 8, the medium calibre gun.

8.6 Studies of alternative designs

Before the design was frozen, two studies aimed at the Type 23 requirement were given careful consideration. One of these was a 'fresh look' at the Type 23, carried out by YARD under a contract from MOD. The other was a Private Venture design proposal submitted by Thornycroft Giles & Associates Ltd (TGA).

6.1 YARD Study

YARD was requested to examine critically the NSR in order to identify where changes or amendments to the NSR might lead to worthwhile reductions in UPC or running costs of the ship, or might lead to improvements in the ship's effectiveness. Arising from this tudy, YARD was then asked to embody a number of the suggestions for possible cost savings into a comparison design, which could be considered by MOD alongside the Type 23 ship design being progressed by YSL.

A main theme of YARD's design lay in the deliberate provision of greater displacement and more space for the equipment and operating personnel than would be customary if normal British warship design practice had been allowed.

8.6.2 Increased displacement

The increased displacement was provided so that heavier but cheaper materials and a heavier but cheaper structural design philosophy could be used. By the adoption of a combination of longitudinal framing of the decks and bottom with transverse ship's side framing, together with the use of offset bulb plates in lieu of Tee bars with the consequent elimination of many brackets and other high cost steelwork, YARD hoped to effect a substantial reduction in steel working man hours. As these are known to be up to a factor of three greater on a warship such as a frigate than they are on a merchant ship such as a cross channel ferry which is not too dissimilar in size and scantlings, there appeared to be considerable scope for saving.

The provision of greater space was intended to have a pay-off under three main headings. Firstly, the provision of much easier runs of piping, trunking and cabling, kept quite clear of all removal routes. Secondly, man-hours savings during the fitting-out process when workmen often trip over one another. And lastly, to ease the conditions in such traditionally congested spaces as Command and Control Centres.

8.6.3 Superstructure reduction

A feature incorporated in the YARD design was a considerable reduction of superstructure, with many of the spaces normally accommodated in the superstructure rearranged below No 1 deck in the larger ship. This had the advantages of reducing the radar signature and of providing increased options for the siting of weapons.

8.6.4 Alternative machinery configuration

YARD proposed an alternative CODOG machinery fit. This was less expensive than the CODLAG fit but only just met the basic noise targets. It was not quite as quiet as the CODLAG installation and had no margin for the future.

8.6.5 Summary of YARD design

The YARD design was a well thought out concept and adequately validated in its main technical features. Although it was not adopted as a whole, a number of its ideas have been incorporated in the developing Type 23 design.

8.6.6 The S90 Design

The TGA design known as the S90 would have conferred radically different characteristics on the Type 23. It attracted much publicity and there was some political enthusiasm for it, so that we not only did an in-house study but we also had the design assessed by the independent Defence Scientific Advisory Council (DSAC) and YARD.

8.6.7 Broader beam

The major TGA claim to be established was that for a given length, displacement and speed, it is possible to increase beam by about 40%, compared to conventional destroyer hulls without any increase in installed power. Although this claim was still 'to be established', the proposition was fundamental to the S90 design. TGA believed that a full-scale hull would give results very much better than ship tank trials, thereby suggesting that established laws were incorrect. According to our calculations, at a displacement of 2,600 tonnes the ehp of the S90 was 28,000 compared with a Leander at 14,000 at a speed of 28 knots. In many ways, it proved very difficult to compare the S90 with the Type 23 because the S90 as submitted did not have sufficient space to meet the Type 23 NSR and the displacement quoted was seriously underestimated. At the corrected dimensions and displacement, the top speed fell far short of the Type 23 requirement and it was considered quite impracticable to instal sufficient power to meet the requirement.

8.6.8 Seakeeping

Major claims were made about seakeeping. TGA figures indicated a roll period much less than that for a conventional frigate. The S90's roll period would have been close to the modal frequency for Atlantic waves with a consequent high probability of resonant rolling. The effectiveness of weapon systems would have been jeopardised and the ability of the ship's company to fight the ship in the North Atlantic imperilled. The comparison of pitch and heave motions showed that there was little difference between the two hull forms.

8.6.9 Capability as an ASW platform

The S90 design also fell short in other important respects. The platform would have been too noisy for towed array, the towing speed inadequate and the lines forward too full for good flow over a bow sonar. The upper deck length would have been too short for a satisfactory weapon layout and the ship would have had inadequate ability to withstand normal damage requirements.

The other major claim for cost reduction due to the use of simple commercial structure and diesel engines remains unsubstantiated. The former aspect has been incorporated to a degree in the Type 23.

The detailed comparatives studies of the two designs carried out by YARD and the DSAC confirmed our own assessment that the S90 design failed to meet the requirement on most of the important characteristics and that some claims made on its behalf could not be substantiated.

The S90 design could not, therefore, be adopted in this case but there will be other situations when its parameters might be suitable. There are many Naval vessels afloat of low length/breadth ratio.

9. CONCLUSION

The last few years have been difficult ones for warship procurement. I believe, though, that the recent, more aggressive Ministry of Defence competitive procurement policy offers better prospects. More rapid introduction in to service of improved capabilities, greater opportunities for innovation and better value for money are some of the more obvious gains. I have been much heartened by the response to this policy from shipbuilders and defence companies.

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DISCUSSION

Mr P. J. Usher, O.B.E, R.C.N.C. (Fellow): It is a pleasure to be able to remark on Sir Lindsay's paper because I feel it is one of the most interesting that has been presented to us. That is so, because it is so contemporary. I do not recall in our Transactions any paper before which has displayed so much of the thinking behind ship design for the Royal Navy, at a time when that thinking is so fresh. I believe that this is a departure from the past which is to be welcomed. It brings this Institution into a more realistic, and more enviable position, being able to comment at a time when comment may be of some value. My own feeling is that, for too long, we have had historical papers. This is by no means that. So, Sir Lindsay, I am delighted to thank you for a most interesting paper.

As for questions, I will limit myself to two main points. One is to ask you whether the time scale which has elapsed in the Type 23 satisfies you? You have shown the processes being followed in this design and incidentally, you have outlined the cardinal points specification which we look forward to working to. Three years have so far elapsed since this design took form, and you have shown us today how it has evolved. It is still, I think, not a ship order. I would like to ask you about the time scales that you see applying to ship design in the future, with particular reference to the rate of development of the weapons which go in those ships.

I commented about the cardinal points specification because I think that is a departure which we must learn about. I welcome it, because you are going to specify the problem, not the solution. That can only be good for the designers in the industry.

Finally, I note that no reference was made in the paper to the Type 21 frigates. If that design was different from contemporary ship designs, it was in respect of time. Our President was, I think, the author of the time scales relating to the Type 21. In brief, the ship was initiated in 1967 when there was a need to fill the gap following the Leanders. Although the Type 22s were to be the Leander replacement, it was thought that they would take longer to design than was acceptable, and we at Vosper Thornycroft, with Yarrow, produced a design in a time scale which was satisfactory.

The net result was that the in-service date, in the light, I might add, of very difficult problems with the machinery fit, which although supposed to be standard with the Type 42 had not by that time been fitted in the 42, the in-service date from the endorsement of the Naval Staff Target was some $6\frac{1}{2}$ years, whereas in the Type 22 that same elapsed period was 10 years. So my comments, Sir Lindsay, are related in most respects to time.

Professor R. E. D. Bishop, C.B.E., F.Eng., F.R.S., Hon. R.C.N.C. (Fellow): A well known First Lord of the Admiralty was moved to say that 'It is one of the happiest characteristics of this glorious country that official utterances are invariably regarded as unanswerable'. His wise words roughly sum up my attitude to the first five sections of this paper. Who am I to argue? But the sheer complexity of the Naval Staff's needs adumbrated in those sections poses problems of such difficulty that the best way of meeting them is far from obvious to me.

To come directly to the point. I am sceptical about retention of the present method of procuring warships. That is to say, I wonder how much longer Section 6 of this paper will be thought tenable.

The need to provide a technical back-up for the Controller seems obvious, and I should like to make some observations on three functions that it should presumably serve. Before doing so, however, let me repeat that my concern is with the future rather than with the past.

The Provision of Wisdom Born of Experience

When the Chief Constructor of the Navy of the day warned the Naval Staff that the design of HMS CAPTAIN was defective he was overruled. The ship was lost in September 1870 within weeks of going into service. Now the Chief Constructor of the Navy was merely pointing out that, in his professional experience, insufficient emphasis had been placed on ship hydrostatics in the compromises that had inevitably to be made in CAPTAIN's design.

Since those days the scope for professional technical experience has increased enormously. Moreover, the risks involved when that experience is ignored or forgotten have not diminished. (Parenthetically, one could not help noticing that important lessons seemed to have been forgotten or ignored in the design of some ships that took part in the Falklands Campaign. Nor did one hear the rumble of heads rolling as a result of this failure).

Perhaps the reference to HMS CAPTAIN gives the impression that the Controller needs to be surrounded by greybeards who have 'seen it all before'. That is not quite the point. For if it were, it would lead inexorably to ship design based on old wives tales. To give a single example, it is commonly held that a ship's strength is most at risk amidships and that that strength can best be determined by imagining the hull balanced in particular ways on certain specified 'heaps of static water'. In its day this was a perfectly sensible and rational approach based squarely on experience. But to continue to adduce this sort of 'experience' when large power enables today's comparatively filmsy hulls to be driven at high speed in heavy seas is risky. Unfortunately, the step from 'heaps of static water' to anything more refined—if only to improve the level of the empiricism—is a step into a different order of complexity; it cannot be made by the unskilled.

The point I am trying to make, then, is a double one. Firstly, the Controller needs to have access to technical experience whose importance has to be very carefully evaluated for the purposes of reaching sensible design compromises. Secondly, the necessary evaluation may be difficult and costly. The 'seen it all before' attitude will not do by itself and I wonder if adequate allowance can be made much longer for this awkward fact with ever decreasing manpower resources.

The Acquisition and Maintenance of Specialist Naval Technology

There are two respects it seems in which naval design differs from civil. First of all naval ships are generally speaking of higher performance. Thus, for example, the effects of slamming and of noise emission cannot be shrugged off. In addition, naval design raises technical problems that are peculiar to warships. This latter distinction is particularly obvious at the ship/weapon interface, in submarine design, and so forth.

This need of the Controller's for access to specialist technology raises questions of education and training. The necessary expertise is not to be found in its entirety within our universities. Yet to try to produce the necessary engineers in-house is to risk introversion and the repulsion of entrants having high intellectual calibre.

It is where naval architecture is concerned that I have some experience of addressing this conundrum. Although the scheme that has been worked out produces really splendid members of the RCNC they are not numerous enough both to man the technological (as opposed to the managerial) side of things and to satisfy the wish of very interested bodies outside the MOD to acquire their services.

There is a problem here and a satisfactory solution will only be found on the basis of discussion and consideration of many factors. One cannot help hearing snatches of what appears to be a prolonged debate on the subject. But those snatches are not exactly reassuring and seem far too much like the sound of axes being ground. In particular, a recent lightly classified report on this and related matters was a real gem of misapprehension.

Keeping up with Technology

Such are the demands that the Naval Staff makes, warship design is beginning to call for skills that lie well beyond what is normally called for in conventional ship design. If proper regard is to be paid to ship vibration, hull distortion in a seaway, noise propagation in and from a hull, loading actions due to slamming and scores of other phenomena, the Controller is going to have to rely more and more on outside agencies. Warship hull design is becoming 'high technology'.

This is quite inescapable not only because the international literature is expanding rapidly, but also because manpower and other resources within the MOD are contracting. To quote a concrete example, the Ship Department has achieved great things with its GODDESS programs. The work could only have been done by a dedicated group of highly professional constructors; but to expect those same constructors to do the technological pioneering that their predecessors did right across their profession in the more spacious days of the past, would simply be foolish. For them even to be aware of what is going on outside, let alone to assimilate it, is becoming too much to expect. And so there is a danger that the Controller will become insulated from some aspects of modern technology.

To sum up then, the Naval Staff feels bound to ask the Controller to perform a very difficult task with very limited resources. This is a situation which is getting steadily worse. Over the years successive Controllers have continually modified their departments by reason of this diminution of resources. I wonder if the time is not approaching when the very philosophy upon which warship procurement is based will have to be re-examined. What role should the Procurement Executive play?

Mr J.F. Leathard, B.Sc., Ph.D. (Fellow): A prominent feature of the paper is cost—the word appears, qualified in some way or other, in many sections of the paper. But, on the whole, the qualifications fall into two groups—relative and absolute. Relative where one design is compared with another, as in the case of the Type 81 versus the Type 14 or where a modification is compared with some base cost as in the discussion of the development of the Type 23. Absolute where some limitation is being quoted, again as in the case of the Type 23 where the initial UPC was set at £70m at September 1980 levels or the initial Type 12 at £3·5m was considered to be too expensive!

The question immediately arises as to the criterion for measuring cost. Fig. 9 suggests that about 25% of the cost—i.e. Hull plus Outfit and Furnishings—are under the direct control of the shipyard and, presumably, the other sectors—Weapon Equipments, Auxiliary Systems, Electrical Generation and Propulsion—also contain an element of installation cost. But how are these shipyard costs assessed? Relatively, they may be fairly easy to derive and are presumably based upon some sort of regression formulae obtained from established data. Since differences are under consideration, it does not really matter whether the base figure is correct or not. Absolutely, as base figures, they are much more difficult to derive and must depend, to some extent, on the advice received from the lead shipbuilder. That there is some uncertainty in this area is revealed by the comment relating to the Type 42 that 'length was thought to be a big factor determining UPC'—this suggests that perhaps even relative cost is difficult to determine, particularly if the changes from the basic are too great and the regression equations become inapplicable.

This discussion leads to two considerations which can be briefly reviewed. First, are the absolute costs under the control of the shipyard set at the correct levels? I find it difficult to believe, for example, that steel working manhours are three times as great for a frigate as they are for a ferry—or, if they are, then they should not be. Obviously, YARD attempted to deal with this situation for the Type 23 derivative by suggesting the use of transverse framing in some parts of the structure instead of longitudinal framing. But, from limited experience of the construction of small warships, I wonder whether much of the apparent manhour excess is a reflection either of rigid imposition of standards and inspection and continual modifications by the purchaser or of the different attitudes in the warship building yards compared with the merchant shipbuilding yards—the former perhaps working in a less competitive environment than the latter who are subject—particularly nowadays—to the strong commercial pressures of a fixed price contract. It would be interesting to learn whether the same differences generally appear between warship and merchant ship steelwork costs in the small number of mixed yards still operating in the UK.

Secondly, production engineering and its most important component, design for production. This is a growing aspect of merchant ship design and every characteristic must be combed to ensure that the most efficient compromise is reached between performance and production considerations. But is a warship treated in the same way? I suspect not and it may be that there is scope for showing significant cost savings and thus contributing towards the quest for better value for money, mentioned in the Conclusion. This is particularly important in relation to the link between the design and the lead shipbuilder.

One of the essential elements of design for production is that the ship design, from the earliest possible stage, must be related to the shipyard in which the vessel is to be built. Clearly, a following shipyard will always have problems in accepting production information from a lead shipbuilder.

Finally, some appreciative comments on the overall content of the paper. It is timely that the RINA should hear an authoritative voice describing the procedure involved in the defining and procurement of a warship so that the 'lay' members of the profession and the general public might be aware of the care and patience involved in ensuring that the correct vessel is finally adopted.

Mr G.H. Fuller, R.C.N.C. (Fellow): First of all may I congratulate the author on a very clear and succinct paper which I think the Institution has sorely needed, indeed the whole shipbuilding industry has, as even we who are fairly close to the MOD, and perhaps have not long left it, have difficulty in understanding the mysterious ways of their systems prior to design development and the construction of the first of class. So, we have here an absolutely seminal paper in helping us to understand this particular area. May I make three points.

First, the author clearly brings out, I think, the need for proper time and effort to be devoted to the study and requirement phase. Time must be enough but not constrained in such a way that we start production and then have to change again. On the other hand, we must not get into the cycle of never starting. However, paper, or perhaps today, computer time, is still cheaper than steel, and as I say, change in build is very expensive. I may mention here that our investment in computer aided design in British Shipbuilders is absolutely enormous and this is going to make a great deal of difference to the effectiveness of the production process.

Secondly, I think we need to watch the concept to, what I call, the design being. By this I mean the availability of an up to date design on the shelf which moves naval ship design forward in an orderly manner. Without such design processes we soon get into irrecoverable gaps in time. In the UK I think we have been fairly safe in recent years. The Type 23 is perhaps late enough to follow the Type 22, and the Type 2400 is all too late after the OBERONs. Nevertheless, not too bad. In other countries, major gaps have occurred and I look with some concern at the huge gaps that have occurred in the USA in their SSN and frigate programmes. Again, a question of the time problem that others have addressed.

Thirdly, I think we have to be very careful in moving ahead at this time with the evolving style and structure of Western shipbuilding. Long cycle time and the huge value of each ship creates a very lumpy order book which is now hitting an ever increasingly fragile industry. We do welcome concepts of competition but we too will have to be commercial in our response and the conduct of our business. We will have to respect commercial confidentiality, much of our information will become more and more sensitive as competition increases, and I think it is also necessary to recognise that there are very major changes in the shipbuilding industry yet to be undertaken, some yet to come to fruition, but many in the pipeline. So, we are very ready for your new concepts and we look forward to them.

Lastly, may I say a word on exports which I think is extremely important and is going to be more important for our industry. We are often accused of poor achievement in recent years. It is true, I think, that the destroyer—frigate area, which is now addressed by many shipbuilders in the West, and soon to be by those in the Far East, is a particularly difficult area. But in the specialist market, submarines, carriers, MCMVs, we have a very cyclic order book. I think we are increasingly having a very attractive product range emerging in this country. At the cheap end of the market, and some of them are not too cheap, the world of patrol craft, landing ships, etc., our achievements are good and I think people should look at what we have achieved in the last few years in this area. Looking at naval exports, I think it is not only a question of price and performance, credit politics, and not least, the desire of many countries to use shipbuilding as an engine for their own industrialisation, are important considerations.

On a final note, I think also as far as the warship is concerned there is the joy of launching a warship in your own country, from your own shipyard, and this is quite an important feature.

Professor K.J.Rawson, M.Sc., R.C.N.C., F.Eng. (Fellow): I would like also to express my pleasure at welcoming a Controller of the Navy to a live debate at this Institution. A hundred years ago, as the Transactions bear witness, all members of the Admiralty Board here enjoyed a fierce and open discussion, both of naval strategy and tactics, and the materiel which would suit those tactics. Today that debate is fragmented. It takes place elsewhere and it is frequently divorced from technology, and therefore, reality. Ideas elsewhere are transformed consequently directly into pseudo fact, by which the advertisers may ply their deceits, and the enthusiasts may indulge their rhetoric. It is a relief, therefore, to find a paper which solemnly examines how the procurement process for a warship, in the face of hostile publicity, finally achieves a sensible balance among the many conflicts which beset every customer-contractor relationship —cost, the offensive payload, the defensive payload, the standard of living and so on.

In Section 7, the Type 23 contrasts very markedly with the procurement of the Type 42. In the late 1960s the economic crisis and public opinion pressurised the designers, and the naval staff, and the politicians, into reducing every standard in that ship, to produce the cheapest possible way of conveying Seadart to the middle of the Atlantic, where it would see few other ships. The consequences, incidentally, were very well known and accepted at the time.

The Type 23 design which began in the middle of 1980, began by cutting standards yet further, the Government persuaded by some fairly irresponsible journalism, coining such words as gold-plating. The Falklands War soon demonstrated the illusion of gold-plating. Public opinion this time, however, has been on our side. It has worked in our favour, and the foolish economies have been removed much to everyone's relief. As a result, the design now represents a new balance, which those who have been associated with it believe, is highly cost effective.

The procurement process as it has evolved for this ship bears rather more examination. Like Peter Usher I was deeply concerned with Fig. 6 which describes the time taken in the procurement process; the bureaucracy, had it been minimised, could now almost have had the ship at sea. It is a wry comment, but had that been so, of course, it would not have benefitted from the post Falklands activity.

Fig. 4 is concerned mainly with the formal interventions and submissions to which the Ministry is constrained for various reasons. In practice the interventions in, what is inevitably, an exceedingly difficult balancing act occur almost daily and they are deeply debilitating to the process. This raises, inevitably, the question of how the amorphous MOD customer should communicate to the contractor. There are so many conflicting authorities within the Ministry that a filtering design agency in-house is essential if the shipbuilder is to retain his sanity.

Furthermore, I do wonder whether the assessment of the tenders in response to the cardinal points specification can be undertaken late on in a very complex process by people who have not been actively engaged in design for some considerable time.

The paper brings out very clearly the very many options which are, and must remain, the owner's, and those which are open to the rich inventiveness of industry as a whole. There is no need to polarise the factions as has become fashionable of late. The Ministers and the naval staff are likely to need a strong and competent, and unbiased, technological group whose interests are strictly the owner's. They need an industry full of ideas and drive as they have. Many of them are thanked in the acknowledgments of the paper, and I believe our thanks, and the nation's thanks, are due to the Controller of the Navy who managed to remain a stable platform himself despite the exhortations of unprecedented magnitude.

Mr E.C.Tupper, B.Sc., R.C.N.C. (Fellow): The author said that one of his aims was to inform people of some of the background to the design and procurement process, of which, perhaps, many of the public are unaware. I feel sure that he has been very successful in doing that. His paper shows clearly the many conflicting demands the designer and naval staff must meet, the variety of options open to them, and therefore, the great difficulty they have in reaching their decisions. I am reminded of a quotation on the more general aspect of engineering design. It was actually on bridge design, and said:

'The design required a series of difficult decisions, interrelated, and far from the deductive, linear progression often imagined by people without experience in engineering'.

It then went on to talk about 'the trade-offs between simplicity of design, availability of material, and practicability of construction that make engineering an art, rather than simply—or merely—applied science'.

I would add that these trade-offs, these decisions, are difficult enough in a stable environment. Unfortunately, the long time scale of ship design and procurement means that ship designers are subject to changes in the threat posed to our country by our potential enemies, and to changes of political will, of which the author mentioned the 1981 Defence Review as a case in point.

I, myself, took the Type 82 design, the BRISTOL, through the cycle from the first discussions with naval staff, through to placing the contract. I was therefore subject, as the author mentions, to the fact that part way through that process the whole reason for the design disappeared when CVA 01 (the large carrier it was designed to escort) was cancelled. I think, in the circumstances, it would be surprising to say the least, if it were not possible to criticise any design when it is used for real, as our ships were out in the Falklands. It is very easy to be wise after the event, and in the light of the threat actually faced.

It seems to me that it would be a great help if one could reduce the time between concept and acceptance into service, and if we could replace our ships more frequently. In both cases our ships might be more up to date technologically, and able to deploy the very latest weapon systems.

The number of Committees concerned in the approval of designs is very daunting. I would like to ask the author whether he feels that this process could and should be streamlined, in order to get through these phases very much more quickly than is possible at present. I am reminded of the saying that a camel is a horse designed by a committee. Of course, in the middle of the desert the camel might be a better creature to have than a horse.

The question of replacing ships more frequently has, I know, been considered. It reduces the need for growth margins and removes the need for mid-service modernisations. The modular approach that has been considered helps reduce the effects of change when changing from one role to another, but it has disadvantages. I wonder if the author would like to say what he feels is the optimum life of a ship.

Mr F. D. Penny, C.B.E., B.Sc. (Eng): What I have to say bears some considerable relationship to what was said by Professor Bishop and by Professor Rawson, perhaps because we shared some recent experiences.

I think that opportunities to learn lessons from real operations are, thankfully, rather rare. So, it is all the more necessary that when the opportunity does occur the lessons are learnt thoroughly and are remembered for as long as they are relevant. We have heard from Sir Lindsay that the lessons from Operation Corporate are being incorporated in Type 23 to a very considerable extent. I am very glad to hear it. But many of those lessons were not new. I believe that Nelson's Captains feared fire above almost all else, and experiences in World War II, and some accidental occurences since then, have spelled out the lessons again. Yet, many of the ships deployed in the South Atlantic were less resistant to fire and smoke than they ought to have been. For this, the blame does not rest mainly with the designers, but, I believe, it was the result of deliberate risk taking in pursuit of economies in first cost, for which we have since paid dearly.

You, Sir, have said that the first stage in design must start with an assessment of the perceived threat. I believe that if no effective counter can be devised, which is affordable, it is no use wringing one's hands and saying, 'Oh well we must do the best we can within our budget'. That is a prescription for wasting money and resources. Instead, it is necessary to rethink the whole situation and either accept a different allocation of overall resources, or define and quantify the risk which it is proposed to accept, and take appropriate actions thereafter. If a well balanced design cannot be produced within the budget, it is foolish and dangerous to tinker with it to achieve a target cost. It is better to go back to square one.

I am encouraged, by what you have said, Sir, about the later stages of development of Type 23, to believe that a well balanced design has, in fact, been achieved, but I hope that you can assure us that in future hard earned lessons will never again be lightly abandoned.

Mr J. Neumann, C.B.E., B.Sc. (Eng), F.Eng.: On this question of time scale, of course, there are many factors involved and I sometimes wonder whether there is not a correlation between the time scale and the size of the naval technical staff. I am not joking entirely because I worked with a relatively small Navy some years ago and we were able to work fairly fast.

The Controller's paper lists important design requirements and processes. I would like to comment on two of these, namely, the cost of the ship, and the problem of comparisons.

We have already had some comments on costing methods and they are somewhat in line with my remarks. During the work which the Controller had asked us to do, to have a fresh look at a ship to Type 23 requirements, we came to the conclusion that the conventional wisdom which says the smaller the ship, the cheaper it will be, is not necessarily correct for a modern warship of this type. Our study suggested that a simpler hull construction offers a heavier but cheaper product. Furthermore, an extra 10% of space will also ease congestion, reduce fitting-out costs, and lead to a net saving, provided that there is enough discipline to prevent the inclusion of additional equipment.

These are statements which I believe to be true, but I have no way of proving, largely because the methods of cost estimation in general use are somewhat crude. But, if I am right, this matter must be an excellent candidate for detailed analysis.

The second point I would like to mention is the subject of comparisons. We are all familiar with one sort of comparison, as carried out, for example, by the Consumer Association, and reported in its magazine Which? Several products are purchased, tested, compared for price, performance, and durability. Even then sometimes Which? cannot come up with a best buy and has to be content with several awards of good value for money. How much more difficult are the comparisons that we attempt? Not only do we not know the answers, often we do not know the question. Worse, sometimes we have to try and compare proposals on the one hand based on a good background of well documented experience, with on the other hand, some new, and as yet untried and untested scheme. Now I am not sure whether this is not even more difficult than trying to compare two speculative designs against each other.

During the Type 23 work, many decisions have had to be made on the basis of comparative analyses. One of these is in respect of underwater noise performance, particularly important in a ship fitted with a towed array, and has a major effect on the selection of propulsion machinery. In the Type 23 the Controller showed the solution adopted, relying on fixed pitch propellers, driven at the low quiet speed by direct drive electric motors, which in turn derive their power from diesel generating sets. There are, of course, other possible solutions, some of which are now being adopted by other navies. It will be interesting indeed to look back in due course and make comparisons in the face of design problems solved, and based on results in service. Which was the best buy, or were they all just good value for money? Any view which Sir Lindsay can express on this would be much appreciated.

Sir Eric G. Yarrow, Bt, M.B.E. (Fellow): Admiral Bryson is the twelth Controller of the Navy with whom I have had a close business association. Without exception they have all, with varying degrees of success, frustration, and failure, tried by some means or other to reduce the number of modifications and alterations carried out during the design and construction of naval ships, and not only prototype ships of a class.

Some years ago when building a ship for the Royal Thai Navy, I think I am right in saying there were eight modifications. In constructing a ship for the Royal Navy, at a time when I was more closely associated with shipbuilding than I am at present, the number must have run into many hundreds. I do not know what the situation is now, but I speak as a tax-payer in saying they cost money.

I remember many years ago meeting an American Admiral, who said that in the United States they try to get their ships out quickly, even if they are only 90% up to date at the time of completion. He went on to say, you British seem to seek ships 100% up to date, and surely, he said, this must involve significant extra costs and possible delay. Probably, the United States order ships in sufficient batches to enable the freezing of one batch—a practice the Royal Navy can hardly afford, anyhow to the same degree.

Inevitably equipment, particularly weaponry, is developing at the same time as a ship is constructed, and Sir Lindsay has mentioned the special factor, of course, of the Falkland Islands War. But I wonder whether Sir Lindsay sees, particularly at the time of procurement, any economical solution to the problem which would be acceptable to the naval staff, or does he see the current practice continuing, as the only practical way to obtain naval ships with the right type of equipment at a price and delivery that he can accept?

Cdr P.T.Thornycroft, V.R.D., R.N.R. (Fellow): I would like, before starting, to echo, if I may, Sir Eric's remarks. I thought they were particularly appropriate as we come, both of us, from what one might call, the commercial shipbuilding side, and may have had at times the same problems.

May I also say that I imagine some of you in the room here today may be anticipating that I wish to rock the boat. We have had, I know only too well, differences of opinion, and it is not part of my, shall I say, task today, and it is a pleasure, to add anything to what has already been said. I would wish the Controller to be aware of this. The Type 23 is an established design and no doubt, from what we have heard and what we have seen, it will answer the requirements. We are not any longer concerned with the Type 23, Sir.

However, I would like to say that I think the Controller's paper has given the opportunity for many of us to have a clearer insight into the problems with which he, and his Department, and the MoD are beset. This is absolutely excellent. I do know from what I hear from all quarters that what I am pleased to call our wide-bodied design, if I might steal that from the aeronautical industry, has attracted discussion, it has attracted attention, and if I am not mistaken, now it is attracting very considerable attention from all walks of life. I think, therefore, it should be considered fairly carefully in future designs.

I started this, if we may call it, wide-bodied idea, more than ten years ago when we did some designs for the Mexican Navy. They were small ships 112 feet long, known as the Aztecs. Twenty one were, in fact, built on the Clyde, and subsequently, I believe, a further thirty have been built in Mexico. As far as I am aware they have done well. Now, they were very much wider, in proportion to length, than we were ever considering subsequently with our new approach. So, although we went wide we may be coming back a little, the width of the Aztec was appropriate for the smaller craft, in my opinion, and they seem to have served them well.

We have little time, Sir, and there are lots of others who wish to speak. I do not, for one moment, wish to take up all your time with the finer points of the Controller's paper. I would wish to submit written comments later which I think would be very much more appropriate. I will say that we are not satisfied with the announced shortcomings of our proposals. We do not agree with them and we even find today a further, should I say doubt, has been cast about horsepower, as we came into the meeting today. It would be impossible for me to keep pace with that at the moment, but we will write and make some observations if we may. I think that would be more appropriate.

I must say I agree with, if I may refer to him as Mr 'Historian' Brown, that the most dangerous and difficult people to deal with, in any project, are the enthusiatic amateurs. This does not only apply to shipbuilding. If you were designing a wheelbarrow I am sure they are just as alarming. However, I did look up in Chamber's Dictionary the description, Sir, of an amateur. I was interested to find that the description was that it is:

'A person who is particularly concerned with the study of a subject for the pure love of the thing, and not for commercial reasons'.

With great respect, I think we have only done it for love so far, and we have not had a great deal of that, but I trust it may happen that way in the end. I hope you will excuse that remark.

I wanted to say one more thing on these sort of lines. I, and my family, have been associated with—in fact my cousin, Mr Barnaby, I think started—the Royal Corps. We have to respect them and those in the positions. But I do pick up the fact that they are constructors, and I think, should be constructive. It is so easy to pick holes in other people's efforts. If is the easiest thing in the world, and I am quite sure that if we wished to, we could point at them, but that is the last thing we wish to do. We would like to work with them.

I think that there is definitely some justification in having further consideration for certain requirements of, what I would call, this wider-bodied approach. I think that designers must look to new ideas if we are to make progress, and surely we must do that, especially for the export market. I cannot believe that the design, and I hope you will all listen, can be entirely without its merits. We have in the last few days, this perhaps is surprising, and perhaps even disappointing, received instructions to complete a design to be built in Japan of all places, which we would much have preferred to be done here. But, we had to be the servants of those who want to employ us.

I will leave that with you, because I do think that something more could be done in this country to encourage new ideas. We have a tremendous lot to learn, admittedly, but I do think, and I would leave with you the fact that other countries are interested, and it would be a pity if this all went by, and we found in years to come that people were to say 'what a pity we didn't think rather harder about it'.

Mr D.L.Giles, B.A.: I was not expecting to say anything because I am only a guest, I am not a naval architect, and I cannot really add very much to what Peter Thornycroft has said.

But I think I would like to point out that in the case of some of the publicity that has attached to the Type 23 Competition, we were approached by the State Broadcasting Corporation, by the BBC, and told that there was to be a programme on the Type 23 Competition and that it was going to include people like Admiral Bryson and others, and would we like to have our say.

So it was not arranged by us. I do not claim to have the power to move the BBC to say what suits my book—I can assure you of that—and I think I would also like to say that although there has been some acrimony (and there have been certain very unpleasant times for me and for others no doubt) we have learnt—and I think the public has become much more aware—of the enormous importance and excitement attached to the design of warships.

When I moved into this business from the aircraft industry, it struck me that there was very little discussion and very little real public interest because so few of the public ever became aware of the Navy and ships except on Navy Days; but I think that now it has become a really interesting and exciting area of public interest. I do not intend to make many public statements; in fact, we have made no statement concerning the S90 since the decision of the Controller was taken last October.

However, we will continue to state our case (within the Industry); and the latest information based on the latest seakeeping trials is that the case is not entirely without merits and it is not quite as gloomy as some people might have suggested last summer. So, I do not think it is a bad thing that the public are interested in Naval Design. I think it helps everyone; as it did in the last century when it was responsible for so many great developments.

Mr D.K.Brown, M.Eng., R.C.N.C. (Fellow): The author and several of the speakers have spoken at some length on the effect of cost constraints on modern warships. Now cost is a very difficult subject but it is only part of what is loosely called 'investment appraisal' which involves cost benefit analysis in some form or another. What we have so far not fully succeeded in doing is quantifying the benefits, and this is a very much more difficult subject. Ultimately, one has to say 'What is the benefit of defending this Realm?' I think probably everyone in this room would say 'Very high', but not everyone would agree with this.

Now, I believe there is one way in which one can approach the quantifying of the benefits of differences between ships if perhaps not in absolute value, and this is through their availability to fight. My colleagues and I in previous papers have shown that it costs at to-day's prices about £100, 000 to get one frigate to an operational area for one day, and if, when it gets there its operational capability is limited because it is noisy, because the motions make it impossible to operate the weapons or the helicopter, that value is impaired or lost.

So taking seakeeping as a fairly simple example, one would note that a frigate of Leander size will have its fighting capability severely impaired in Sea State 6 and reduced to something approaching zero in Sea State 7. In this way one can obtain, multiplying the lost days by £100, 000, some idea of how much it is worth paying to improve the seakeeping of that ship. I believe that it is possible though even more difficult to adopt such procedures to quantify the benefit of reducing the noise and improving other features of the ship design in itself.

If I may speak very briefly in commenting on one or two of the previous discussers, I would like to pick up Sir Eric Yarrow's point about the Americans not making changes to their ships. A very interesting example was the large number of Escort Carriers built in World War II for the Royal Navy by Seattle Tacoma Shipyard. They totally refused to make any modifications whatsoever to these Royal Navy ships and there were a considerable number of alterations which the Royal Navy thought were essential for the type of war that they were fighting. Eventually, a happy compromise was found and these ships, immediately they had left Seattle, were taken up to Vancouver for what, I think, was a five week re-fit in which the changes the Navy thought were essential, were made.

Finally, if I may have two seconds on perhaps a light-hearted note and pick up Cdr Thornycroft's definition of 'amateur', I totally agree with him. If I were designing ships for 'love', they would be very different ships from those which I have to design to meet the constraints of operational requirements and costs.

Cdr M.B.F.Ranken, R.N. (Fellow): Most of the points that I had noted down have been covered by the twelve who have preceded me.

I ought to start by saying that, as I am the only Naval Engineer Officer who has stood up so far, it is a delight for me to see a Naval Engineer Officer, the first one ever, as Controller, though, being a steam plumber (not of the Watergate variety), I would much of course have preferred the first one to have been one of ours, since the Navy's marine engineers have their origins about the same time in the same excellent schools that produced the Royal Corps, as anyone can read in last year's Centenary Paper(8).

Admiral Bryson now heads, I believe, all the naval engineering disciplines brought together in the Royal Corps, a development which is long overdue, though I fear that the vital input of sea experience is much reduced from what I remember, and I hope that that can be rectified.

This paper is close to being Sir Lindsay's swan-song from his first career, and another great Controller is in the Chair, also on the last straight of his third, or is it his fourth, or maybe his fifth career, as our President. That has embraced a most frustrating period of great change in the engineering profession, during which he has tried to guide us forward and give us the courage to merge our Institution with the Institute of Marine Engineers (and maybe some others) into a potentially greater, certainly much stronger body of professional engineers of the sea, not hide-bound by irrelevant academic disciplines of the past, totally divorced from the real working lives of most responsible people in it.

Admiral Griffin is now dedicated to persuading Britain to build a strong maritime future based on the fact that the Free World is totally dependent on the sea, most especially on maritime transport, without which there could be no world trade, economic prosperity or even survival for very many countries, including most of the industrialised ones like our own.

Getting right what this paper describes is just one very important element in securing our maritime health in peace, and survival in war, and those Generals and Air Marshals and Civil Servants who think that, when war starts, the West can suddenly do without shipping—and the Navy perhaps?—better get their heads examined.

But the Royal Corps really must not assume unto itself the fount of all knowledge—even if the Kaiser was a bit off his rocker, as they told us last night on television. Not all amateur ideas are nonsense, nor are those of non-specialists, whether they are seamen or otherwise. Some of them had a dreadful time getting brilliant ideas adopted, and that experience is not limited to this field. But if you read the history of naval and military procurement over the last 180 years, there are umpteen cases where things took an awful long time and cost a great deal of money, even when they were desparately needed, in wartime just as much as in peace.

More important, professional ideas have had just as bad a time down the years at the hands of the arrogant and the complacent and the 'not-invented-here' brigade. The 'short-fat' ship is only one of them, the latest of those ideas where not a shred of real proof has actually been forthcoming to show that it cannot be made to work, perhaps even better than its own protagonists presently claim.

But, whether this one is right or wrong, what is essential is to find some way out of the impasse about which we have been talking today, of spiralling costs that are rapidly killing the Navy—*all* Navies except Gorshkov's.

There are statements in the paper which absolutely amaze me, and should amaze anyone else who stands back from his place in one of the many hot seats and thinks dispassionately about what is going on; none of these people are going to get very far until they resolve a number of deeply entrenched and fundamental problems. The many-headless bureaucracy which we have built up, especially since 1964, is one reason for our present, almost total impotence which allows the Treasury misers to make mincemeat of us, and the politicians to get away with murder—and only very rarely carry the can.

And that is not so different from what we had during the 40 years before 1871, when the Naval Lords were so busy dealing personally with the detailed humdrum administrative matters arising out of what had been the Navy Board (today's PE (Navy)), that they never had time really to stand back and think about policy, strategy or future planning; the Board structure after that year lasted until 1964, and the Naval Staff grew around it, especially after 1918.

I will stop at that point, but I do implore people not to go on thinking that we can continue the present impossibly tortuous and long drawn-out procedures, and expect to have a Navy of any substance by the end of the Century.

Added in Writing after the Meeting

Those who denigrate amateurs might remember that one definition is a man of taste, a purist, a precisian, and 'there should be a dash of the amateur in criticism, for the amateur is a man of enthusiasm who has not settled down and is not habit-bound' (Brooks Atkinson, July 8, 'Once Around the Sun';

1951). That surely applied to Sir John Isaac Thornycroft to the end of his days, born into a family of sculptors, always a lover of form; that is what his grandson Peter Thornycroft is today, building on the art of Sir John, not much enamoured of the stupid computer which is no artist, least of all an amateur, however precise its dull calculations.

I hope no one is suggesting that a professional cannot also be an amateur and an innovator—unless of course he joins the Royal Corps? I prefer David Brown's quotation from that great Director of Naval Construction, Sir Stanley Goodall 'In the Navy List after the name of each ship is a column headed 'By Whom Designed'. That fixes the individual responsibility for the ship, mark for you, not for part of the ship'. (Ref. 1). Sir John and Peter Thornycroft would not dissent from that; nor I suspect would have Sir Rowland Baker, sadly lost to us this Spring, that arrogant egotist who spoke last year about triumph and enthusiasm and ships that 'are better today than ever before!'

One other point that must be made is that high academic standards have seldom spawned major innovations initially, though they may later have refined them. Good engineering is almost invariably simple in concept, hopefully also in execution.

The main part of the paper limits itself to describing 'the development process applied to a particular warship to meet the operational requirements ...' (Section 6). Perhaps that should inhibit comment on the earlier sections. However, Section 2 reflects a serious omission from recent Defence White Papers, and Cmnd. 9227/1984 is no exception; that is no mention at all of merchant shipping, which prompted strong comment from the Select Committee on Defence in its recent First Report, Session 1983/84, Statement on the Defence Estimates 1984, 436, 22 May 1984. We should note also the very worrying decline in our Merchant Navy, and those of our NATO partners, to the extent that there is most serious doubt that singly or collectively they could fulfil the three major tasks which must be carried out by merchant ships—reinforcement and resupply shipping, economic shipping (today far larger in volume than in 1945), and STUFT in support of the Royal Navy and all kinds of military operations (for few of which are the RFAs ever likely to be sufficient). There must also be a substantial surplus of capacity over and above the aggregate of these tasks to allow for losses. Finally, there are the so-called 'force multipliers' which in this context covers the adaptation of merchant and miscellaneous shipping to all kinds of naval tasks; but today there are virtually none of the huge number of ships which were taken over in two World Wars, mostly without significantly jeopardising the main tasks of merchant shipping. Mahan's well-known observation that 'the necessity of a navy ... springs ... from the existence of a peaceful shipping, and disappears with it. ...' is as true today as 95 years ago; so is his teaching that sea power is not synonymous with naval power, something which Gorshkov has taken very much to heart, but the United States seems to have totally forgotten; I hope we have not, in spite of the Government's incredible apathy towards all things maritime, what some are calling the 'sunset industries'; we could be forgiven for supposing that the Royal Navy is included in that category, to judge by the inordinate priority lavished on the central front in Europe—but not apparently on the vital supply lines essential to sustain it.

The Navy's primary task as in previous wars is to ensure the passage intact of the maximum possible number of surface ships and the vital cargoes they carry. Not for the first time it has to perform this essential role in the face of major new offensive concepts against which effective counter-measures that can be sustained in general war have yet to be proven, assuming that they already exist. Before World War I we convinced ourselves that age-old well-tested strategies were rendered obsolete by new technology and weapons, and were close to losing that war in 1917. Between the wars most that had been learnt was set aside, and many ignored the aircraft, whilst others placed blind faith in the early ASDICs. Since World War II old strategies are again being questioned, in the face of spectacular advances in offensive technology—nuclear-powered submarines, aerial, surface and submarine missiles, satellites and precision electronics—so far inadequately matched by detection systems and defensive weapons and decoys, and the tactics to go with them. Perceived Staff Requirements for every class of ship are presently calling for outfits of capabilities which are largely beyond realisable concepts, or alternatively are pricing all major assets so high that no country, or even Alliance, can afford enough of them to come anywhere near performing the much larger primary task that still has to be undertaken.

The paper describes very well the principal defensive systems needed by individual independent ships, as presently envisaged, but making individual warships so costly that they become worthwhile targets in their own rights. What remains to be seen is how these essential capabilities can be expanded and deployed to defend merchant and other non-war ships in transit, either in very many escorts including submarines, in aircraft, or on board the merchant ships themselves, as was normal in days past, or a combination of all of these and other ideas.

There is clearly a strong argument for going back to first principles and looking again at possibilities in the light of rapidly changing technology. Let us hope the new Naval Sections of the Defence Staff will have the capability to generate more substantial technical inputs at the concept stage than has been possible with the expertise available within the Naval Staff these past 40 years.

Under Section 3 more might have been said about the so-called 'Tapestry' tasks, which, if given proper priority in peacetime, when they are at least as important as any other naval task, can generate very useful assets for all sorts of secondary tasks in war—OPVs, fishery protection vessels, SAR, surveillance aircraft. In passing, one might ask why no mention is made in the paper of the Hong Kong patrol craft—the Peacock Class—admittedly in dire trouble at present, but potentially useful assets in the defence of shipping and home waters.

These earlier sections are littered with observations about organic aircraft and helicopters—for which land-based aircraft are almost never a credible substitute, except in coastal waters, whatever the light-blue PR 'whiz kids' may try to claim (land-based aircraft have a very different but essential complementary role in some sea areas). What sticks out a mile is the absolute necessity of coming to terms with economical solutions both for flying and for accommodating aircraft in many types of surface ship—VTOL and helicopters, possibly VSTOL, and certainly airships (moored overhead when necessary). This requirement needs space on board and really good seakeeping and roll and pitch characteristics, genuinely stable and capacious platforms, most of them, including all the warships, as small and low in unit cost as can be devised, if we are ever to have anywhere near realistic numbers—and hence a credible Navy.

The byzantine ramifications of the procedures described in Section 6 should fill everyone, not least the author himself, with absolute horror. As a method for 'the Navy to determine how best to carry out its allocated tasks within the constraints of the defence budget' it is hard to imagine anything much worse. 'War ministries ... are really nothing more than a complex of committees; and a committee is a contrivance by which persons who can separately take no decisive action, come to the conclusion that no effective action can be taken; while it is a built-in characteristic of a technological committee to obstruct'. (R. H. in a book review, Naval Review Vol. LII July 1964). 'Full consultations' there may be, but how many people come to those committees prepared or able to compromise? Worse still, how many chairmen have the authority and the experience to impose their wills, as one suspects the best of the old DNCs were able and willing to do, though whether they were the right people to accept that responsibility is another matter? Committees in such a heirarchy are highly incestuous in their membership, of the essence of the British way of life, easygoing and inefficient'. (Lt-Gen. Sir Frederick Morgan, 'Overture to Overlord', Doubleday 1950).

But even worse is the appalling time scale from first initiation and definition of a new requirement to delivery of the first of class; 12 years is shown for the ship in Fig. 6 and it could apparently be 15 or more years for a new weapon system installed in it. Allowing for a 25 year life and no mid-term modernisation, that means 40 years, equivalent to entering World War II with equipment started at the turn of the 19th Century—before the submarine came into service, the Wright brothers proved heavier-than-air flight, and Marconi's wireless started the whole field of electronics, quite apart from the DREADNOUGHT herself, said to have been built in a year and a day.

Not only is this absurd, but there is little possibility of continuity for those in charge of each project, none at all for any serving Naval Officer. And lack of continuity also means changes in policy, maybe fundamental changes in requirements, necessitating alterations and additions, further delay, and inevitably heavy extra costs all round, all before any operational experience can be obtained to prove that the overall concept and its individual systems are anywhere near right. The Invincible Class did take 'rather a long time'! struggling to survive the political defeat of 1966 over the unrealistic CVA01, not least against the RAF's nonsensical claim to be able to provide air cover for the Fleet, presumably anywhere! Time is immensely costly both in money and in obsolescence, and most of the delays in the bureaucratic process are really aimed at satisfying the pedestrian desire of accounting officers to ensure that every single pound and penny is accounted for beyond any danger of criticism from the Treasury, the Comptroller and Auditor-General or the Public Accounts Committee. That the result is in fact much higher costs before anything goes into service, and therefore eventually fewer ships, maybe even another Defence Review, doesn't seem to occur to anyone. It is very convenient to talk of 'defence inflation'; how much of that is genuine, as opposed to purely bureaucratic? Mention is made of the danger of 'playing safe' but that is exactly what is done today in pursuit of accountability without real responsibility.

Surely the statement in Section 6.1.2 that 'of course, there are no prototype warships' is far from reality. Any first of class after seven years is bound to be a prototype, and anyway what is wrong with it being so-designated? The fault in the past, between the wars and with the Daring Class just afterwards, was that operational commanders would not treat these ships as being in any way different from normal fleet units. With the very high unit cost of modern ships, would it not be sensible to learn from the aircraft industry, and plan from the start to build prototypes of the ships (platforms) themselves, and seek to make each design the best that can be developed in terms of performance and seakeeping, and capable of carrying a wide range of different equipment outfits for different operational tasks? Time could be very well spent in refining hull forms in model tanks, just as is commonplace with aircraft in wind tunnels. With a standard range of good platforms, we might even revert to three or four years from concept to first of class. The Blohm & Voss Meko is a special version of this kind of thinking.

Section 7.1 talks about the 'Second World War requiring high calm water speed'. Surely that is what we got, rather than what was really needed. Destroyers (and cruisers?) were expected to keep up with fixed-wing aircraft carriers, but all the destroyer classes, smaller predecessors of today's major warships, were seriously affected by sea state, and in the case of the Atlantic convoys extensively damaged, miserably uncomfortable, and incidentally desparately short of endurance, as is amply documented in various memoirs and histories and novels. Today, very high speed has little operational significance, but 25-28 knots in high sea states (5 to 7) would certainly be valuable; that is what the short-fat ship aims to offer even in its smaller sizes. It is very much to be hoped that the Type 23 will manage it also, as well as good seakeeping at low Towed-Array speeds. Could the author please give the current estimate of the total cost of this so-called 'cheap' frigate?

Peter Thornycroft and David Giles will no doubt deal comprehensively with Section 8. Having followed the quite scandalous and unrelenting process of vilification of the Azteca/Osprey/Sirius/S90 family of designs, and seen the sea performance of the smaller vessels and the tank tests and 1/10th-scale model comparative tests of the S90 with a Leander, I have not the slightest doubt that the S90 is on the right lines, and could readily be refined on aircraft lines to be even more superior than it already is to anything we have at present—including the Leander 'one of the most successful warships of all times'! For me, the whole of Section 8.6, in so far as it refers to the S90, is at best out of date, certainly pessimistic, and at worst deliberately misleading.

'He that will not accept new remedies must expect new evils' (Bacon). Otherwise we are condemned to further escalating costs, recurring 'defence reviews', more cut-backs, reduced credibility, eventually a coastal navy with no capability. I hope there is no mempsimus in any key position in the Royal Corps or elsewhere in the system.

REFERENCE

8. Thomas, K.H.W.: 'The Royal Corps of Naval Constructors: A Centenary Review'. Trans. RINA, Vol. 125, 1983.

The President then proposed a vote of thanks to the author which was carried with acclamation.

WRITTEN DISCUSSION

Mr R.W.S. Easton, C.B.E. (Fellow): The author is to be congratulated on a first class paper explaining as it does the new look in naval warship procurement.

Question time recorded that there is still, however, a marked lack of understanding of the relative costs of modern warships from the various countries of the world, also the misconception by some of the alleged easy times of warshipbuilders compared with their counterparts in the merchant building yards.

In real terms the costs today of Type 22 and Type 23 Frigates compare very favourably with overseas units of comparable size and comparable capability. The apples and oranges syndrome is overplayed, one requires to compare like with like and the British do themselves down at every turn. Any fool can take a contract, but it requires a good man to refuse one. Buying work is not an answer to improving productivity, nor is the comparison of inefficient over-capacity in shipyards with those creating capacity through efficiency.

Those yards which are currently quoting for MOD(N) and overseas work will acknowledge that the price base is extremely lean, and the alleged fat is non-existent. In addition, to stay in this market on a long term basis requires considerable investment, both in plant and people.

The large warship suggested as a better alternative to the more compact ship is also somewhat of a myth. If the compact ship is properly designed for production and for maintenance in the longer term, then its advantages are easily seen. It saves volume, which requires to include additional weight, fittings, piping, ventilation, electric cables, etc., and associated maintenance over the years and in certain cases complicates docking facilities, dues, etc.

The compact ship is also quite capable of being designed to heavier scantlings, so again there is no argument.

Since only 30% of a modern warship is under the shipbuilder's direct control, the remaining 70% from sub-contractors, including weapon suppliers (40%), requires equal careful scrutiny, when adverse comments are made of the shipbuilder by ill-informed critics.

Mr I. H. Wakeling, M.Sc., R.C.N.C. (Member): This paper clearly explains the processes by which the final design of a warship is agreed and I am sure that it will be used as a reference work for many years. That is until a further paper explains the process following the next Ministry of Defence reorganisation. However, I would not expect any reorganisation to change the basic underlying principles of consultation, debate and formal agreement. As indicated in the paper, it is the relationship between the procurement authorities and the contractors that will develop. On this particular theme it would be interesting to know Admiral Bryson's view on how the proposed reorganisation of the Defence Staff might affect the procurement process, in particular the high level decision making; will it speed up the process?

As stated in the paper, the design of a warship involves a series of trade offs to achieve the most effective solution within the cost and other constraints imposed. The decisions made in this process are the most difficult to make and will always be open to criticism in the light of experience and when slightly different circumstances, from those envisaged, arise.

In assessing the effectiveness side of cost effectiveness, there are a number of different approaches. First, the customer (i.e. the Naval Staff) can make the decision purely based on personal experience and opinion. This leads to as many ideas as personnel involved and can cause frequent changes of emphasis. Secondly, there is the wholly 'scientific' approach of Operational Analysis with defined scenarios and massive computer modelling. This is very open to the accusation that a different scenario or different assumptions could give a different result and that flexibility is a big element of a warship which cannot be modelled. Thirdly, there is the balance between the two with Operational Analysis providing a further input to the decision making process. It would be most interesting to know how Admiral Bryson sees the role of analysis in the decision making process and how he sees future developments in this area.

Analysis of operational capabilities and requirements will become even more important with the increasing reliance on industry to design warships based on a contractually sound statement of requirements. The assessment of whether a design meets the requirements and the comparison of the total capabilities of competing designs whilst still only on paper will be a major challenge. There are many factors to be considered, hull performance, weapon performance, availability, survivability, cost, etc and some structured approach will be required to produce some measure of total effectiveness. Admiral Bryson's views on the way ahead would be a most interesting addition to the paper and the presentation.

Mr R. K. Pudduck, O.B.E., R.C.N.C. (Member): Having recently served as the Staff Constructor with C IN C FLEET I am conscious of the operator's priorities in assessing the design features and performance of our warships. Whilst with the Task Force in the South Atlantic I saw at first hand the effects of cannon, bomb and missile used against ships designed in some cases over 20 years ago.

Given that some ships were bound to be hit—the damage was more or less as predicted beforehand. Exocet trial firings against HMS UNDAUNTED in 1976 showed the severity of damage to be expected from this weapon and certainly no commanding officer of a more modern frigate or destroyer expects his ship to survive many direct hits from HE iron bombs. (It was suggested that HMS ARDENT was hit by up to thirteen 500 lb bombs—not all exploded of course).

Whilst great strides have been made since WW II to develop efficient point and area air defence systems, absolute self-protection against all forms of attack is undoubtably unrealistic. However, in a limited engagement when losses are particularly expensive (and probably of immediate public concern) the battle-worthiness of every war vessel becomes highly important. The ability to 'float' and 'move' may then rate on a par with the prime ability to 'fight'.

It is also sensible to guard against the cheap kill. Bombs and missiles do not invariably explode on impact, there will be near misses and small calibre projectiles can cause disabling damage. The threat of fire exists both in peace and war, but given priority, solutions are readily available to reduce the risk, for example by minimising inflammables and installing protection systems. The Falklands experience has given a filip to making good these deficiences. The costs will be considerable, especially for retrofit, but our ships will I believe be ultimately more capable. It is encouraging to hear of improvements being built into the Type 23 frigate.

On a different note and again reflecting South Atlantic experience, I have an observation about refuelling at sea. In the RN, this is a well practised evolution generally conducted without a hitch. But the logistics of arranging rendezvous with the RFA and the vulnerability to attack particularly during the transfer suggests that there is scope to improve the flexibility of the fleet by increasing the endurance of frigates and destroyers.

Professor D. Faulkner, B.Sc., Ph.D., R.C.N.C., F.Eng. (Fellow): The author and his staff are complimented on an excellent paper giving a clear description of the complex procedures for procurement, together with some interesting technical data on recent designs. This will form a notable addition to our Transactions.

Undoubtedly the recent changes in procurement policy stem from the belief that more economic designs might result. This, of course, has to be proved. An immediate example stemming from the current Type 23 naval frigate design is the decision by the contractor to depart from the traditional longitudinal framing of warships to a system which incorporates only transverse frames in the side structure. It is claimed that this will save cost, perhaps with a small penalty in structural weight (and figures like 4% have been quoted). I believe that such policies could lead to cost savings, although I am not in the least convinced that in this particular case they will be significant and they may not even be real. What I do believe is that they are very likely to cause some weakness in shock resistance simply because of the inherent difficulty in making structural connections with this type of structure.

The main point of this discussion is to suggest that more studies leading to such decisions need to be made. Some could be conducted in-house but many could usefully be extra-mural studies. We have been fortunate at Glasgow University to obtain one such contract from the Royal Navy to make comparisons between the costs of differing structural arrangements, each satisfying the necessary design requirements for strength, etc. I hope the author and his staff will continue to promote such studies. Even though the Navy's record is very good in this respect, there are certain areas where improvements can still be made. This paper is a very helpful background to such thoughts.

Mr M. Barrett, B.Sc. (Eng), M.Sc., R.C.N.C.: Section 4.1 indicates that for frigates the flight deck must be at the after end. Indeed on a typical frigate the centre of the flight deck is some 40% or more of the ship's length aft of amidships.

The ability to operate helicopters depends greatly on motions at the flight deck, in particular on vertical velocity. The position at which the flight deck will experience minimum vertical motion is some 15-20% aft of amidships. Table III shows rms vertical velocity at two alternative flight deck positions for a frigate in head seas.

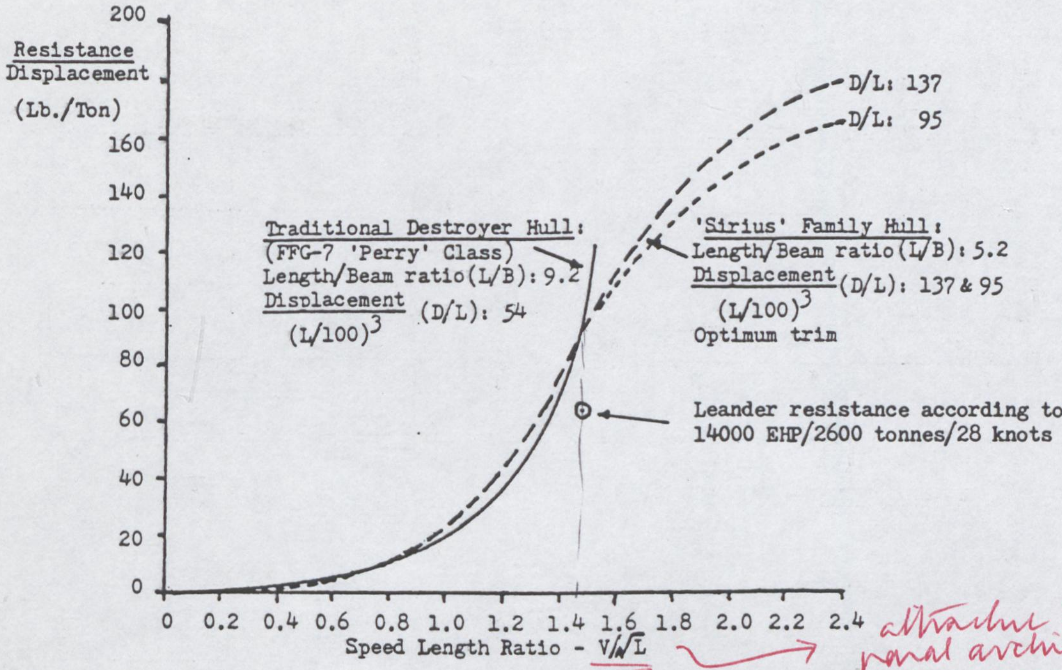

Fig. 13. Non-dimensional Comparison of Hull Resistance

attractive because naval architects recognise it for set geosims of same V/√L gives geometrical identical wave patterns.

TABLE III

Sea State	rms vertical velocity (m/s) for flight deck at: (a) 17%	(b) 42% abaft ⊗
7	1·23	1·65
6	0·87	1·26
5	0·56	0·80
4	0·35	0·49

It can be seen that for the case of the flight deck nearer amidships, a given motion occurs in conditions roughly one sea state greater in severity.

Supposing the frigate with the after flight deck to be able to operate helicopters up to sea state 6, the more centrally placed deck would enable operations up to sea state 7. In the Northern half of the North Atlantic this would make operations possible on average for an additional 2½% of the time, i.e. 9 days per year, and this percentage would increase considerably as the area of operations moved northwards.

It is recognised there are sound reasons against such siting of the flight deck. Nevertheless, such a gain in potential operability must make siting the flight deck as far from the aft end as possible a highly desirable aim for the warship designer.

Mr D. L. Giles, B.A. and Cdr P. T. Thornycroft, V.R.D., R.N.R. (Fellow): We would like to answer some of the comments made by Admiral Bryson in his paper concerning the S90 design.

The S90 validation exercise was undertaken by Thornycroft, Giles and Associates (TGA), Frederikshavn Vaerft of Denmark (FV), British Aerospace Dynamics (BAe) and other UK companies entirely at their expense save for the assistance of a small DTI research grant. It was suggested by the Minister of State and endorsed by the MOD; and, from the outset, it was clearly understood to be merely a basic appraisal of the performance and seakeeping qualities of this hull form with a minimum of structural and systems research. It was in no way comparable to the detailed and MOD-funded Type 23 design studies which had already been undertaken by YSL and YARD.

Within the UK warship design and building community—with so many companies, universities, learned societies etc., so dependent upon MOD-derived funds—it is very difficult to find a truly 'independent' body of opinion to comment on such a controversial design as the S90. S90 is bound to be competitive to the interests of both Ship Department and British Shipbuilders and, therefore, is not likely to receive a very sympathetic appraisal, whatever its merits; nor is that surprising, in the circumstances. Also the YARD S90 Appraisal being largely classified 'secret', inhibits detailed public discussion—by TGA at any rate.

Dealing with Admiral Bryson's specific comments, we would like to turn to Fig. 13 in which the resistance curve for our

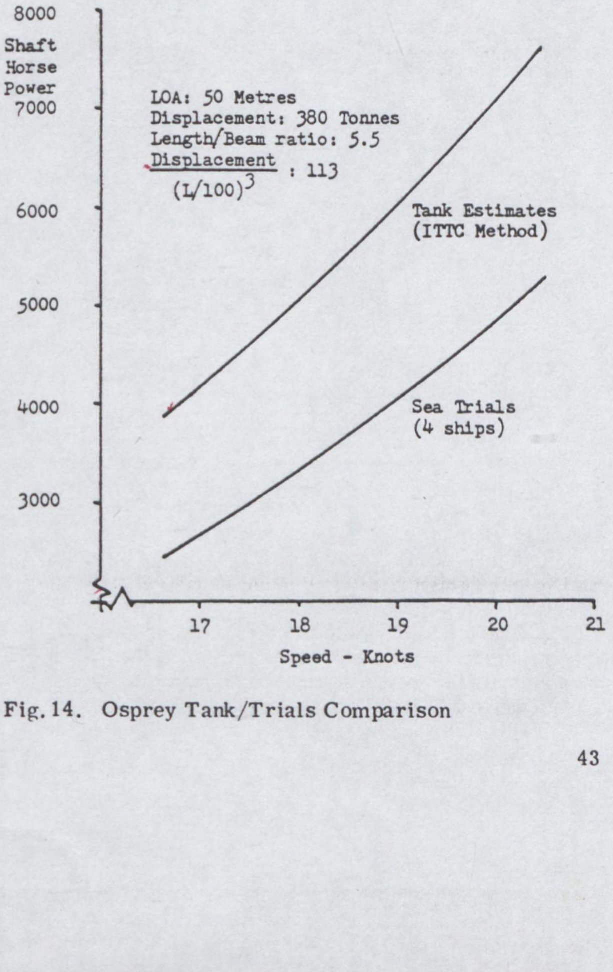

Fig. 14. Osprey Tank/Trials Comparison

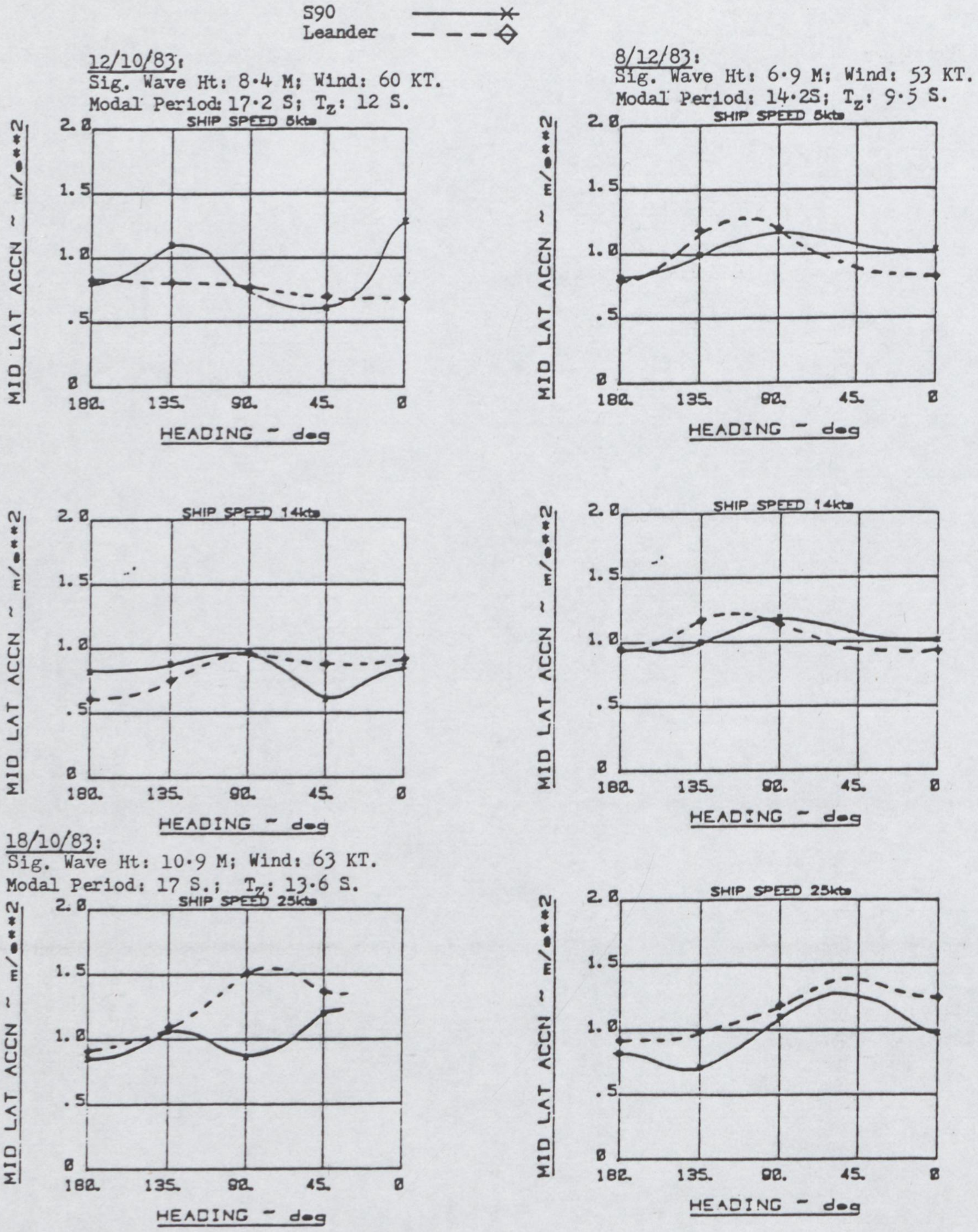

Fig. 15. RMS Midships Main Deck Lateral Accelerations

Sirius family of designs—which includes S90—has been compared, on the same non-dimensional basis, with the resistance curve for the American FFG—7 Perry Class frigate (Ref. 9). We are told by a member of the RCNC that the latter is an efficient modern form. The graph shows that, despite having a beam which is some 60% greater than the Perry Class, at the same length and displacement, the S90 has similar resistance characteristics up to $V/\sqrt{L} = 1 \cdot 45$; and thereafter is increasingly less resistful. As Admiral Bryson says, this is fundamental to our design family; although it has yet to be established in full scale at a frigate displacement. However, it has been established in the case of our smaller Osprey and Azteca designs in full scale; and our views that such resistance characteristics will prevail at frigate displacements are supported by leading international physicists and by the current Chairman of the British Towing Tank Panel. To deny this is to invalidate tank testing of our designs at greater full scale sizes. Finally, the performance of the new Hong Kong Patrol Craft as described in the February 1984 edition of The Naval Architect must confirm similar resistance characteristics to our design family at $V/\sqrt{L} = 1 \cdot 8$ to $2 \cdot 0$ and confirms the pessimism of the ITTC method for this type of hull form at larger sizes; and the powering factors applied by YARD to S90 would indicate a speed of only about 23-24 knots, for the Hong Kong craft, rather than the 28+ knots achieved on trials.

Fig. 14 compares the Osprey propulsion test results with the full scale trials results; and it is clear that, at 20 knots and the same displacement, the power predictions are about 40%

TABLE IV. Joint Frequency of Occurrence of Significant Wave Height and Modal Wave Period (sec)

Significant Wave Height (m)	Modal Wave Period (sec)															
	3·2	4·8	6·3	7·5	8·8	9·7	10·9	12·4	13·8	15·0	16·4	18·0	20·0	22·5	25·7	Total
24	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0
20	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0
16	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0
14	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0
12	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·2	0·0	0·0	0·0	0·2
10	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·1	0·3	0·3	0·0	0·0	0·0	0·7
9	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·2	0·4	0·2	0·0	0·0	0·0	0·8
8	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·3	0·7	0·4	0·2	0·0	0·0	0·0	1·6
7	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·2	0·8	0·9	0·4	0·2	0·0	0·0	0·0	2·5
6	0·0	0·0	0·0	0·0	0·0	0·0	0·0	1·4	1·2	1·1	0·5	0·3	0·0	0·0	0·0	4·5
5	0·0	0·0	0·0	0·0	0·0	0·0	0·7	3·2	1·4	1·1	0·4	0·3	0·0	0·0	0·0	7·1
4	0·0	0·0	0·0	0·0	0·0	0·6	3·4	3·5	1·3	1·0	0·5	0·2	0·1	0·0	0·0	10·6
3	0·0	0·0	0·0	0·0	0·8	4·6	3·9	3·3	1·4	1·0	0·5	0·2	0·1	0·0	0·0	15·8
2	0·0	0·0	0·0	2·0	5·5	5·0	3·3	2·5	1·3	1·0	0·4	0·3	0·1	0·0	0·0	21·4
1	0·0	0·2	2·7	5·2	3·9	3·1	2·2	2·2	0·9	1·0	0·4	0·2	0·1	0·0	0·0	22·1
0	0·2	0·2	2·5	2·2	1·6	1·8	1·1	1·0	0·4	0·4	0·2	0·0	0·0	0·0	0·0	11·6
Total	0·2	0·4	5·2	9·4	11·8	15·1	14·6	17·3	9·0	8·5	4·4	2·6	0·4	0·0	0·0	98·9

S90 Tests

Date	Significant Wave Height (m)	Modal Period (sec)
8.12.83	6·9	14·2
12.10.83	8·4	17·2
10.10.83	10·9	17·0

Calculated by: BHC Test Facilities from information provided in Ref. 11.

higher than those actually measured in full scale with great accuracy by the testing tank concerned. Again, conventional factors are pessimistic.

We have never claimed any better performance for S90 than predicted by BHC and NMI Ltd., resistance and propulsion tests; MOD and YARD have simply claimed that the performance would be very much worse. Admittedly our tank predictions made no allowance for sonar dome, fins or fouling, since these must be subject to evaluation in the tank or in full scale before any accurate prediction can be given for this hull form at such a large size; nor were we given any information on the type or size of sonar dome required. Any comments on the penalty on performance of a bow-mounted sonar for this type of design are pure speculation at this stage.

Concerning Admiral Bryson's calculations of EHP for the S90, we are delighted to find that, notwithstanding the implications of his opening quotation, the RCNC are after all subject to human error. In the first instance, his paper proposed an EHP of 24, 900 for the S90 at 2, 600 tonnes and a speed of 25 knots. We contacted his office because this EHP was greatly in excess of the measurements of both BHC and NMI Ltd., (which gave about 19, 000 in the condition specified); we were told that there had been an understandable typing error and that the speed should have been 28 knots. This of course would have been equally inaccurate because, for such a speed, 24, 900 EHP would have been extraordinarily low; and, therefore, we are delighted to see that Admiral Bryson's final figure of 28, 000 EHP for 28 knots is entirely consistent with the measurements by BHC and NMI Ltd. This is important since it clears any doubt concerning the MOD's acceptance or rejection of the S90 resistance curve as shown in Fig. 13; and because it contradicts the view, expressed from highly qualified sources, that the hydrodynamic properties of this hull form which might apply in model tests would not necessarily apply in full scale ships of 400 tonnes and over.

Never having seen an EHP curve for the Leander (we presume 2, 600 tonnes also applies), we cannot seriously comment on the accuracy of an EHP of 14, 000 for 28 knots. If this figure is correct, then it shows that her resistance is some 50% less at $V/\sqrt{L} = 1{\cdot}48$ than the FFG – 7; or – accepting the Jane's figure of 30, 000 BHP for 28 knots–it shows a very low propulsive coefficient, of less than 0·5, which is unusual. In fact, an EHP of 14, 000 seems as difficult to reconcile with a speed of either 25 or 28 knots as was the original figure of 24, 900 for the S90.

We would point out that a displacement of 2, 600 tonnes is only some 100 tons over the published Leander standard displacement. A comparable figure for S90 built to equivalent cost and structural complexity would be about 1, 700 tonnes for which the EHP would be about 17, 000.

Of course it is quite possible to reduce the EHP for our hull form by various tricks which we have tried over the years. One can omit appendages such as the skeg; or one can reduce the waterline beam for lower resistance at lower speeds; or one can reduce displacement. But there are always penalties to be paid, either in cost, handling, seakeeping, or stability. We have found it more acceptable to reduce low speed resistance by changing fore and aft trim because this does not interfere with our preferred hull form; it can also reduce pitching and is most effective at heavier displacements when most transferable fuel is being carried. We do not search for a hull form which is refined entirely in tank and head sea conditions for minimum resistance; for the consequence can be a ship which is uncomfortable — and even dangerous — in the midst of the sea or at the mercy of the Almighty.

Concerning our 'serious underestimate' of S90 displacement, this has arisen because MOD and YARD calculated — on a theoretical basis — that we should require between 50-60% more power for any given speed than shown by the S90 propulsion tests at NMI Ltd., and BHC. For instance, YARD arbitrarily increased the BHC/NMI EHP for 28 knots by 13·5%; despite a measured qpc of 0·607 they recommended 0·512, yet we know that an average for much smaller twin screw ships of our design is about 0·59. The measured (1 + x) factor of the Osprey model/full scale correlation tests was 0·96, yet YARD recommended 1·04; and other unfavourable arbitrary factors were applied by YARD. All this necessitated a massive increase in fuel load to provide the required endurance and, hence, a serious increase in displacement. The questions of structural, machinery and equipment weights were the responsibility of FV. There was some disagreement between FV and YARD over lightship weight, but this did not amount to more than 10% of full load displacement.

Concerning seakeeping, at the time of the S90 validation report, the comparative seakeeping tests between free-running 1/10th scale models of the S90 and Leander had not been conducted and the only information available was based on controlled experiments with a 1/20th scale model in the NMI tank. This was run in similar wave spectra to those which were defined in the famous paper (Ref. 10) on frigate seakeeping presented to the Institution some years ago. No claims were made which were not consistent with the encouraging results obtained from the controlled experiments, which were necessarily conducted only in head seas. The S90's natural roll period was calculated by both FV and BHC to be 8·04 seconds at a GM of 3·59 metres and a displacement of 2,800 tonnes. This compares with the Leander's natural roll period which is 9·3 seconds at 3,000 tonnes and a GM of 0·84 metres. According to Ref. 11 the coincidence of modal frequency for Atlantic waves with the S90's natural roll period would only occur with a significant wave height of about 2 metres; and this would be insufficient to generate any serious rolling according to the seakeeping tests we have undertaken. The critical wave height for the Leander would be about 3 metres (see Table IV).

The free-running S90 and Leander model comparative seakeeping trials were completed in December 1983 and the full report has only recently been produced. Measurements of RMS roll accelerations of the midships main deck position of the S90 and Leander are given in Fig. 15. This point is 1·6 metres higher above DWL in the S90. We attribute the placid roll behaviour of S90 to careful attention to design of the hull, appendages and topsides; and to the vertical distribution of weight. During the three days of measured trials included in these tests, the seas at full scale were consistent with Table IV and there was no evidence of resonant rolling by the S90 at any heading. We would agree that there was little difference between pitch and heave motions of the S90 and Leander; although in general handling, slamming, foredeck immersion, yaw, extreme roll and heel angles, manoeuvrability and other aspects, the S90 was clearly superior — particularly at higher speeds and in the more severe sea states. We would be happy to discuss these aspects in greater detail if called upon to do so.

We would not dare to comment on any of the remaining criticisms without more information, since it was not the purpose of the validation exercise to examine any of these points in detail. We are as conscious of the disadvantages of heavy commercial diesel engines as we are of the advantages; and we consider that, if the Navy is committed irrevocably to the use of light diesel fuel, there is little point in considering the use of heavy medium speed diesel machinery. We acknowledge the attractions of gas turbines and we shall be submitting a CODOG variant of the Sirius family for the OPV III competition.

Since the decision to reject the S90 was made by Mr Ian Stewart in October of last year, we have refrained from making any public comment. We appreciated that an enormous amount of work had already been done on the Type 23 design and we would not have regarded the S90 as more than a very preliminary research exercise. We were not surprised by Mr Stewart's decision at the time, although — naturally — disappointed. A Programme of Work was agreed by the MOD and DTI before the start of the S90 validation exercise; and it was disheartening that such an elaborate — and, to us, costly — programme of model testing, in two separate tanks and at sea, should have been so summarily discarded in spite of such encouraging results.

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Mr M. Meek, B.Sc. (Fellow): I refer specifically to the alternative design which the author mentions as the Thornycroft Giles S90, and which has been the subject of so much discussion and controversy. I believe there is a lesson to be learned and it is that when someone comes forward claiming to have a new design he must expect to have it immediately challenged and scrutinised and therefore he must be prepared to present to a potential customer (in this case the MOD) all the usual design calculations and data necessary to authenticate his design.

I also believe that we need to differentiate between inventiveness and creative design. No new invention is involved in the S90 that could drastically alter either basic design thinking or the basic design principles of naval architecture. It is quite different from, for example, the effect that Parsons' Steam Turbine had on ships; or Whittle's invention of the jet engine had on aircraft design. Therefore since known theory and design practices apply, it should have been reasonably easy for a competent designer to present a preliminary concept that could stand up to professional scrutiny. The history of the case proved otherwise. It is only very recently that a presentation of data has appeared in public as Ref. 12 and which can be openly discussed. The consequences are revealing.

The initiator of the S90 postulates a whole series of benefits attaching to his idea all based on the starting point that, in spite of its unusual wider and shorter form, its resistance characteristics are roughly as good as an FFG-7 Perry class vessel. From that reference it is obvious that what the promoter fails to appreciate or understand is that, although similar curves of resistance per ton of displacement may be produced for the two ships based on speed/length ratio $V/\sqrt{L}$, which appear to be similar, his vessel is much shorter i.e. L is less, than the Perry Class. Therefore the power at the same ship speed could not possibly be the same for both ships. In actual fact, his own figures show that at the same speed of say 25 knots the S90 type of vessel has more than twice the resistance of a conventional hull — a fact that has become apparent elsewhere as he has been persuaded to produce figures instead of 'claims'. Most of his subsequent claims in Ref. 12 as to advantages and benefits are therefore suspect since a penalty in power of this magnitude is not readily overcome whatever the other merits of the concept.

It takes time and effort to design a ship. A merchant ship design concept would, if it were to be taken seriously, have to be supported by an accurately drawn general arrangement plan showing that there is space for machinery, equipment and cargo; by a lines plan showing both the underwater and the above water form; and by a set of calculations proving that there is sufficient power to drive the vessel at the required speed, that the weight of the vessel and its buoyancy are sufficient to provide the required payload, and that it will float in a safe and stable condition. For a warship, the corresponding data must also be produced from the very first presentation of the concept.

It is difficult to conceive a similar state of affairs applying in other branches of engineering where, as in this case, even Government Ministers seemed to be prepared to be misled by what was a concept only, against the advice of recognised experts in the field. In the medical field, someone who presses a novel idea in public and in influential circles without having the necessary evidence to support his claims and who does not accept the criticism of the recognised medical authorities tends to be labelled a quack.

May I now commit a heresy and ask the author whether naval circles will continue to describe and compare their vessels in terms of displacement? He states that there is a mistaken belief (presumably amongst those who allocate funds to Naval Shipbuilding) that cost is proportional to displacement. As we all know it is not; but naval personnel can hardly expect otherwise when they have traditionally used displacement as the measure of size between vessels. The disparity between the displacement and size of, say, a Type 21 frigate and an Invincible Class aircraft carrier illustrates how displacement sometimes conveys little as a comparative term. Modern warships tend to be more concerned with internal space, volume and deck area than weight. So why not use a space or volume measurement for comparison? The new method of calculating gross tonnage could well be used for warships in the same way as now used for merchant vessels.

TABLE V

	Displacement	GT (approx.)
Type 21 Frigate	3,100	3,380
Invincible	19,500	26,900

It is easy to see that gross registered tonnage as traditionally defined, with all its complications of exempt spaces and spurious deductions etc., was wholly useless for describing warships. The gross registered tonnage was intended to convey an idea of the cargo carrying or freight earning capability of merchant vessels, and dues were apportioned accordingly. But the new gross tonnage measurement which came into force in 1982 is a simple calculation based on the internal volume of the vessel. It is expressed as $GT = K \times v$, where the K is a factor related to v and v is simply the total enclosed internal volume. There is no reason why it could not now be applied to warships. Indeed Usher and Dorey (Ref. 13) come near to it when they give internal volumes for their family of frigates and it can be seen that for conventional frigates the gross tonnage thus measured would not be very far removed from the displacement figures, so ensuring that traditional minds would not have an impossible leap to make in their mental appreciation of size. For an Invincible it would, however, be a much larger and much more realistic figure, as shown in Table V.

The adoption of this internationally accepted calculation would then, apart from producing more realistic comparisons between warships, also mean that a 'Reliant' or other merchant vessel converted to naval functions would enjoy a sensible comparison with her sisters still in the merchant service, but also be comparable with naval vessels where size would then be expressed in the same terms.

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AUTHOR'S REPLY

Frigate Procurement Timescales

I would first like to comment on the lengthy periods needed to procure warships and what might be done to accelerate the process. This is a recurring question, which in a slightly different form, asked me if I was content with the time taken to evolve the Type 23 design in to a seagoing warship.

In general, I am not content with past performance. I am sure acceleration is possible and I will explain why.

At the start of a frigate project, as I have explained in Section 6 of my paper, there are concept studies and initial designs leading to the formulation of a Naval Staff Requirement. For the reasons Mr Fuller has given, this is a phase that should not be unduly hurried. However, not all warships are as complex as frigates. Industry has been invited to propose a design for the AOR in response to a Ministry requirement and is being asked not only to build the ship but procure its weapons, integrate them into Systems and deliver an operational ship. It may be possible to incorporate some lessons from this experience into all warship procurement practice.

As far as the Type 23 is concerned, the timescale which has elapsed during its development does not satisfy me and I would have liked to have seen it much shorter. However, in the two years between completion of the original study in October 1981 and final Ministerial endorsement in October 1983, the ship design underwent two major revisions (one as a result of the Falklands war) and emerged as a ship with a more general purpose capability than the original concept. Bearing this in mind, the rate of working of those concerned was most creditable. Moreover, the timescale compares favourably with earlier designs. Since October 1983, much time has been spent in contract negotiations for the build of the first of class with the Lead Shipbuilder. It is neither sensible nor desirable to hurry these matters in the present financial climate.

Attention both in the paper and in discussion has rightly been drawn to the need for the careful phasing of weapons development with ship development. I think that some of the organisational changes in the Controllerate that were introduced in 1983 will benefit this process, especially the setting up of a Directorate of Future Material Projects. One of its primary tasks, within an overall long term ship and weapon development programme, is to run an ongoing weapons development programme not too closely tied to specifically approved platforms. In this way, we can accommodate the lengthier development time needed for the more complex weapon systems.

For simpler weapons and sensors, the cardinal point specification (CPS) procurement system offers several advantages including reduced timescales. CPS involves the Ministry of Defence in issuing to suitable companies a broad specification of what it is we want. It is a pre-requisite that the item is virtually on the shelf or requires minimal development. Industry advises what can be offered and sometimes we have been pleasantly surprised. The competitive environment reduces costs but, in the context of this particular discussion, the important dimension is that timescales for development are negligible, procurement can be rapid and the necessary installation data for the ship designer provided promptly. Timescales will also depend upon the ability of Industry to design the ships we specify because design development now rests very firmly with the lead contractors.

The approval procedures are an evident factor in the frigate procurement timescale and Mr Tupper has commented on the number of committees involved. Typical approvals are illustrated in Figs. 4 and 5 of my paper. Of course, these procedures must be streamlined. This is recognised in the plans for MOD reorganisation. Paragraph 34 of The Central Organisation For Defence (Cmnd 9315) states:

> 'The establishment of the new Defence Staff and the OMB will allow the central equipment committee structure and procedures to be streamlined. There will be a single Equipment Policy Committee to advise Ministers and Chiefs of Staff. The Committee will advise on the equipment production and development programme, and the balance of equipment investment, so as to ensure that they are matched to operational requirements, resources, defence policy, industrial and sales considerations, and technical feasibility and provide value for money. Membership of the Committee will reflect these interests as appropriate and other Government Departments will have the opportunity to attend meetings as necessary.
>
> The new Committee will replace the present Defence Equipment Policy Committee and Operational Requirements Committee and will be supported by sub-Committees dealing with individual areas of the equipment programme'.

We shall also consider very carefully the amalgamation of weapon NSTs with the platform NST so that approvals might cover the complete warship.

Nevertheless, taking up one of Commander Ranken's points, the 'bureaucratic' process has, to a degree, to be carried out. Very large sums of money are involved. I absolutely agree that time is money; this is well understood in my staff. We strive to make the right decisions as rapidly as possible.

Mr Usher's statement comparing the Type 21 development timescale with that of the Type 22 is broadly correct but it must be remembered that the Type 21 was an interim replacement and the normal stage by stage design process was telescoped deliberately. In the case of the Type 22, the normal machinery was followed but was substantially delayed by external factors including a major defence review.

Mr Neumann's version of Parkinson's law that the timescale 'expands' to match the size of the Naval technical staff might provoke a mischievous response! There is almost certainly some truth in what is said but the fact remains that if you are designing and building ships with the capability of a Type 22 or Type 23 to meet a threat that covers all of the maritime warfare spectrum, it is inevitable that a lot of people will be involved. Just as important is the likelihood that a small Navy will not be faced with the same difficulty as the Royal Navy in obtaining financial and political approval at several stages in each project, a process that inevitably builds in delay. It is most important to compare like with like.

Ship Life and Phasing of New Designs

Mr Tupper is correct in his comment that ship life has been examined on a number of occasions and most recently in the wake of the 1981 Defence Review. This caused us once more to review critically the cost effectiveness of major refits and our substantial investment in the Royal Dockyards.

The optimum life of a ship depends on many factors, particularly the type of ship and the propulsion and weapon systems. The current philosophy for frigates is to design for an 18 year life with a certain amount of weapon updating but without the total modernisation carried out in the past. The modular approach does indeed offer a possible way of updating ships and this is kept under review for each design. Some aspects of a modular approach in the form of cellularity (Ref. 14) have been incorporated in the Type 23 Design. During that 18 year life it will be necessary to keep the ship and especially its weapon systems up to date. This will not, though, be achieved by modernisations or major refits as in the past. Relatively short periods will be allocated for updating and our policy is that new equipments should be as simple to fit as possible.

As I have said, new frigate life is based on an 18 year cycle. We plan longer lives for other classes of ship such as the CVS and the amphibious ships—in this instance, 30 years. We note the American programme for extending the lives of their Forrestal Class carriers and, in certain circumstances, it may prove cost-effective to embark on a similar exercise for a class of Royal Naval ships.

As I have said, very many factors determine ship life. One factor I should mention is through-life costs. Manpower is also an important factor since technology generally helps us to reduce this in the newer ships. Every navy will, however, have some very up-to-date ships and some that are less so.

Ship life and the phasing of new ship designs leads me to one of Mr Fuller's observations. We are fully aware of the need to aim for a continuous rolling programme of ship designs not only to provide a means of design improvement but also to retain the necessary expertise and to give a steady work load to Industry. This is a central feature of the DGFMP(N) future forecast, to which I have referred above.

Batching

Sir Eric Yarrow raises an interesting point on batching. In the past we have sought to batch ships within classes, e.g. the County Class destroyers, Leanders and more recently Type 22 frigates and I should not ignore the SSNs, but almost inevitably without complete success. Changes during building are inevitably expensive and frustrating to the work force. On the other hand, the pace of technology is such that we cannot leave a design completely unaltered during the time it takes to build a class and we do adopt batching, admittedly on a much smaller scale than the Americans. Inevitably, any really essential changes are made to individual ships if they cannot await the first refit.

Nevertheless, we are not deterred by partial failure in the past. Identicality across a significantly sized batch is even more important now than it was, especially when the Admiralty Board are striving to reduce the training and support costs of the Fleet. Batch 1 Type 23s will be identical, which also gives us savings from multiple ordering of equipments, and I am confident a similar policy will apply to the second batch.

Commercial Structural Practices and Steelwork Costs

Professor Faulkner expresses some reservation that departures from traditional longitudinal framing may reduce shock resistance. Dr Leathard is not convinced that steel working manhours on a frigate may be three times greater than on a ferry.

On the question of steel working manhours, there is of course variation between warshipbuilders and mixed yards, as well as variation for any given builder, warship or mixed, at various times. These variations lie within a comparatively narrow band (30%) and are due to facilities and methods, the industrial relations situation and yard loading. Alterations during build are not a significant factor in accounting for variations, never amounting to more than a few percent.

The three times difference quoted is for warship steelwork in a mixed yard compared, on a like for like size basis, to commercial steelwork. This large difference is mainly due to the finer warship lines requiring more hull curvature, the more complex sub-division increasing access difficulties, the desired lightweight grillage structure being more subject to distortion during fabrication, the bi-directional stiffening limiting the use of machine welding processes, the greater number and complexity of major and minor seatings required and the shock resistance requirements for continuous rather than intermittent welding of structure.

Many of these features are essential if the warship is to fulfil its function. Commercial structure will also be heavier and this has repercussions on many aspects of ship performance including speed and endurance. I have recently received advice from the DSAC Hull Committee that this area needs more detailed study since available data are insufficient to form a conclusion. I support this further work and we have placed the research contract for a cost optimisation study referred to by Professor Faulkner.

Technical Staff Resources

Professor Bishop very rightly focusses sharply on the question of intramural staff capabilities and, in particular, their ability to keep pace with advancing technology.

First let me assure him that the Ministry of Defence fully recognises the essential need to employ highly skilled professional engineers for use in the warship design area. He can be reassured that we will continue to pay particular attention to the initial and through life training of these officers to equip them fully in both professional and managerial capabilities.

I take the point that we have to seek assistance from industry to develop the initiatives arising in design technology. I believe the arrangements we have made in partnership with industry, and may I say that more are in prospect, will cover the aspects he has raised. Whilst, therefore, we are becoming increasingly dependent on industry for the development of warship design this does not, as I have indicated earlier, reduce in any way the need for the MOD to retain professional engineers such as those in the Royal Corps of Naval Constructors.

Within my own Controllerate, the task of the constructor or the Naval engineer officer working in a procurement job in the future, will not require him to execute a design but to be capable of assessing a design, of being a highly intelligent customer. The task will involve translating the requirements of the Naval Staff, which derive in essence from the threat, in terms which industry can understand. Industry will then respond and define how they would propose to provide a solution to that problem. In making their proposals, I would hope that they will provide a fairly detailed specification, written in engineering terms and written in terms which can be the basis of a formal contract.

The next task of the Staff is to make sure that the interpretation of that specification meets what the Naval Staff want and, furthermore, that what is written into the contract in terms of how that specification is going to be demonstrated will provide a high degree of assurance that, when we finally take delivery of the end product, it will meet our requirements. My staff will be faced not with one solution in-house; they will be faced with a choice from a number of varying solutions and I believe this to be technically a most challenging job. Evaluation of a single equipment, a surveillance radar or an electro-optical sight, can be demanding but as Mr Wakeling observes the problems multiply when assessing whole ship designs.

We shall cut our teeth with the assessment of competing AOR proposals. This will require a minor mobilisation of resources within the Controllerate to examine all the proposed engineering solutions and significant participation by the Naval Staff and Support authorities. Our task will be simplified in a number of ways. The prime contractor will obviously have done considerable filtering of sub-contractors' proposals before submitting his tender. Some systems and equipments are specified by the Ministry and are already approved Naval Staff requirements. However, I do not underestimate the problems of whole-ship design evaluation.

Assessment of designs leads me naturally to addressing Mr Giles' S90 design comments.

The S90

Firstly I must reiterate, as I wrote in my paper, that we are always ready to examine new ideas. The final decision was that the S90 design was unsuitable for the Type 23 requirement but this does not mean that, in the future, we shall not consider very carefully the S90 design for other applications.

I do not agree that it is difficult to find independent comment on novel proposals. My own staff have the interests of the Navy at heart and are very willing to adopt new ideas from any source when evidence is presented to show that these ideas have merit. The Defence Scientific Advisory Council is tasked by the Government with providing alternative opinions where necessary and their views on the S90 proposals were in accordance with those of my staff.

The difficulty in making public comment on the TGA proposals is that they have only been given to us in confidence. In particular, I cannot comment on the errors and omissions in Mr Giles' weight estimates. However, I have been through the points he makes with my experts and as a result I cannot accept his interpretation of Fig. 13. At the same $V/\sqrt{L}$ the resistance/ton for both ships is similar over the range of usable frigate speeds. In this speed range, at the same $V/\sqrt{L}$ and same displacement, the FFG7 will be very much faster than the Sirius 90. Mr Meek has drawn attention to the misleading characteristics of Fig. 13 and has shown that for comparable ships the resistance of the S90 form is double that of conventional frigates. Compared with such a discrepancy, arguments on a few percentage in $(1 + x)$ factor are irrelevant to the theme of my paper. If Mr Giles wishes to pursue this argument he may care to present a paper to the Institution for discussion.

No comment can be made on Fig. 14 since the basis of the estimate and the details of the trials analyses are not disclosed. Tank testing is not a precise procedure but MOD estimates and trials results are very much closer than those of Fig. 14 even for broad forms such as FEARLESS ($L/B = 6\cdot3$). There is nothing here which would offset the high resistance of the S90.

We fully accept the test data produced by BHC and NMI, but we have not accepted all the interpretations Mr Giles has placed upon them. Since he has not been given information on the sonar, we would agree that he could not assess its effect on the ship's performance. On the other hand, we are surprised that Mr Giles did not make some allowance on resistance for the very large roll damping fins fitted to his model.

At the RINA meeting, I apologised for the errors in the paper and I am pleased that we are now in agreement. The EHP (effective horsepower) for LEANDER at 2,600 tonnes is correct and I have included in Fig. 16 a resistance curve for this ship at 2,600 tonnes. The claim that the equivalent S90 is of only 1,700 tonnes we find surprising but since no evidence is produced we cannot comment further.

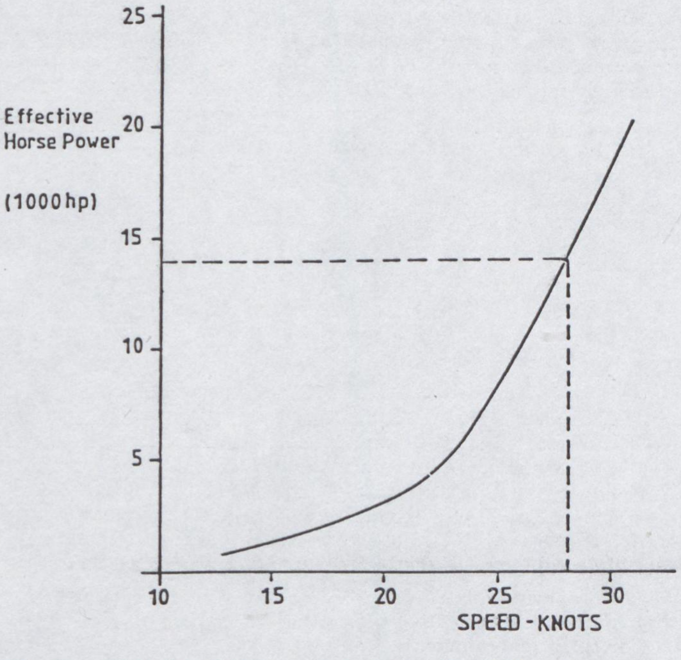


Fig. 16. EHP-Speed Curve for Leander Class Frigate at 2,600 tonnes

The seakeeping data presented are very much what would be expected from a form of S90 proportions. The DSAC report did not consider that the differences in pitch and heave motion between LEANDER and S90 would affect the choice of form. The rolling of the S90 model is certainly of interest. We would expect a shorter roll period than 8 seconds, something of the order of 6 to 7 seconds, as indeed does the DSAC. Certainly if frequencies prevalent in the sea spectrum can be avoided this is advantageous. However modal frequency is only one aspect of the spectrum; considerable energy exists in waves at other frequencies, and of course the encounter frequency is a function of heading and speed as well as wave frequency.

The spectrum quoted is typical of fully developed conditions in the open N. Atlantic. In more confined waters, such as the North Sea, modal frequencies will be lower.

As stated above, large fins were fitted to the S90 model which would assist in damping out oscillation. The bridge of the S90 due to its height would, we believe, experience unacceptable roll accelerations.

We would not disagree that the greater freeboard and draught of the S90 give her considerable advantages in wetness forward and in reducing slamming. However, the limiting speed in bad weather will be governed by pitch and heave motions to the same or slightly less extent than that of the LEANDER.

Finally, in response to Mr Giles' concluding remarks it is surprising that he finds the S90 resistance, which is so much greater than that of a conventional form, to be 'encouraging'. Nevertheless, there may be other concepts or requirements which might be satisfied by the shorter/broader form and I can only reiterate that our minds remain open to such a change should it produce a better overall design.

Warship Production Engineering

Dr Leathard has suggested that production engineering practice applied to merchant shipbuilding should be applied to warship construction with consequent cost savings. In addition, he has drawn attention to the problems of follow-on production shipyards in accepting ship data from a lead shipbuilder.

I agree that we need to give greater emphasis to the requirements of production in our designs. We have made a start in this direction with YSL on the Type 23 and expect to extend this approach. Responsibility for warship design is increasingly in Industry's hands and, so long as we are able to procure new ships by competition, it will be in the interests of the shipbuilders themselves to reduce the costs of construction by good production engineering.

Follow-on warship production should, as far as possible, be competitive. Since it is unlikely there could ever be a universal production documentation system, the follow-on shipyard will always have to adjust the lead shipbuilder's information to meet his needs.

Costs

I have already commented on steelwork costs but there were other questions under this heading. Dr Leathard asked about the assessment of shipyard costs.

I agree with Dr Leathard that absolute costs are not easy to derive. This particularly applies to the first ship of a class, and even more if the first ship is different in size to any recently constructed, for instance the INVINCIBLE and the new design conventional submarine. Even follow-on ships pose difficulties as the programme for a class of ships usually requires up to six to have been ordered before the first ship completes its trials and its actual cost is known.

All major warship contracts let in the last 5 years, following either single or competitive tender, have been on fixed price or fixed price incentive fee terms. Some cost plus contracts were let before 1979 but each of these was converted to a fixed price form of contract before, at the most, 60% of the work had been completed. Thus warship builders are given a positive incentive to reduce costs.

Before a fixed price contract can be agreed, the MOD and the shipbuilder need separately to determine an absolute cost. As far as the MOD is concerned this is worked up as the design progresses using a combination of comparative, parametric and detailed estimating based on data obtained for similar tasks in ships recently completed or about to complete.

Commander Ranken asked me to state the current estimate for the cost of the Type 23 frigate. At the time of writing, contract negotiations with YSL are still in progress but, in response to a parliamentary question (Hansard Col 42 18 June), US of S(DP) replied that the frigate, across the first batch of eight ships, would have an average cost of £110M (at 1983/84 price levels). I do not expect any significant change to this figure. 'Cheap' has a rather unpleasant connotation. I believe the Type 23 frigate is a very cost-effective solution to the Naval Staff's requirement. Its weapon systems are comparable with those of the Type 22 frigate but, for the price of three Type 22s, we shall be able to buy four Type 23s. This is very creditable to all involved and, no doubt, some small solace to the taxpayer.

Mr Pudduck commented on the costs of remedying design deficiencies revealed in the Falklands Campaign. These are difficult to quantify for ships in service as the necessary alterations and addition of new equipment may be carried out during a variety of upkeep periods. I am glad that a considerable part of this retrofit work has been completed.

Costs have not been insignificant. In the case of the Type 23 frigate, the improvements to ship survivability and the fitting of additional weapons capability (my paper Section 8.4) has cost about £9M (at 1983/4 prices).

I believe this is a vital investment. In response to Mr Penny's exhortation that the lessons of the Falklands should not be forgotten, I am in total agreement.

Definition of Ship Size

Mr Meek poses a conundrum—displacement or gross registered tonnage?! He suggests that gross tonnage should be used to compare the size of warships. Space is certainly the more important parameter in designing a warship and in this sense I agree with him. On the other hand, I do not think that the use of gross tonnage provides a better basis for cost considerations. The ratio of frigate cost to that of INVINCIBLE is more nearly in the ratio of their displacements than of their gross tonnage.

Comments on Type 23 Design

Mr Barrett has given a clear presentation of the advantages of making the helicopter landing spot closer to amidships and these figures are used in the consideration of new designs although there is no practical application at the present time. Alternative flight deck positions were considered for the Type 23. On balance, it was assessed that the penalties far outweighed the benefits and the flight deck aft was chosen.

I agree with Mr Pudduck in emphasising the need for increasing the endurance of frigates and destroyers. It is true that these ships are at risk whilst replenishing and rendezvousing with the tanker. However, bigger fuel tanks cost more money and may occupy space that could accommodate other improvements. Refuelling cannot be treated in isolation from replenishment of food, stores, spares and ammunition. Hence the Naval Staff have, as usual, to strike an appropriate balance in setting the requirements for each class. The recent introduction of erodable (self-polishing co-polymer) anti-fouling paint will give us a useful increase in endurance at very little extra cost.

As far as the Type 23 propulsion system is concerned, I agree with Mr Neumann that it will be interesting to look back in due course and analyse our choice of CODLAG. I am s confident as one can be that the performance at low speeds ll enable effective towed array operations.

Role of Operational Analysis

Mr Wakeling poses some interesting questions. Will the current re-organisation of the Ministry of Defence speed up the procurement process? I don't know and am not rash/bold enough to make a forecast. What is the role of operational analyses in the decision making process between competing ship designs? I would answer that it is important and will be more important when we know more about how to handle it effectively. But inevitably it is both scenario and assumption dependent so should be used with care. I agree entirely that in the new competitive environment we will need to develop techniques to ensure that we can trade-off the advantages and disadvantages of contending designs. I would think investment in a few models simulating various aspects of warship performance with varying parameters may be one useful route to explore and indeed that is currently being done.

Conclusion

I should like to thank all those who have participated in the oral and written discussion of my paper and stimulated further thinking about the manner in which we design and procure modern surface warships.

REFERENCE

14. Gates, P.J. and Rusling, S.C.: 'The Impact of Weapons Electronics on Surface Warship Design'. Trans. RINA, Vol. 124, 1982.

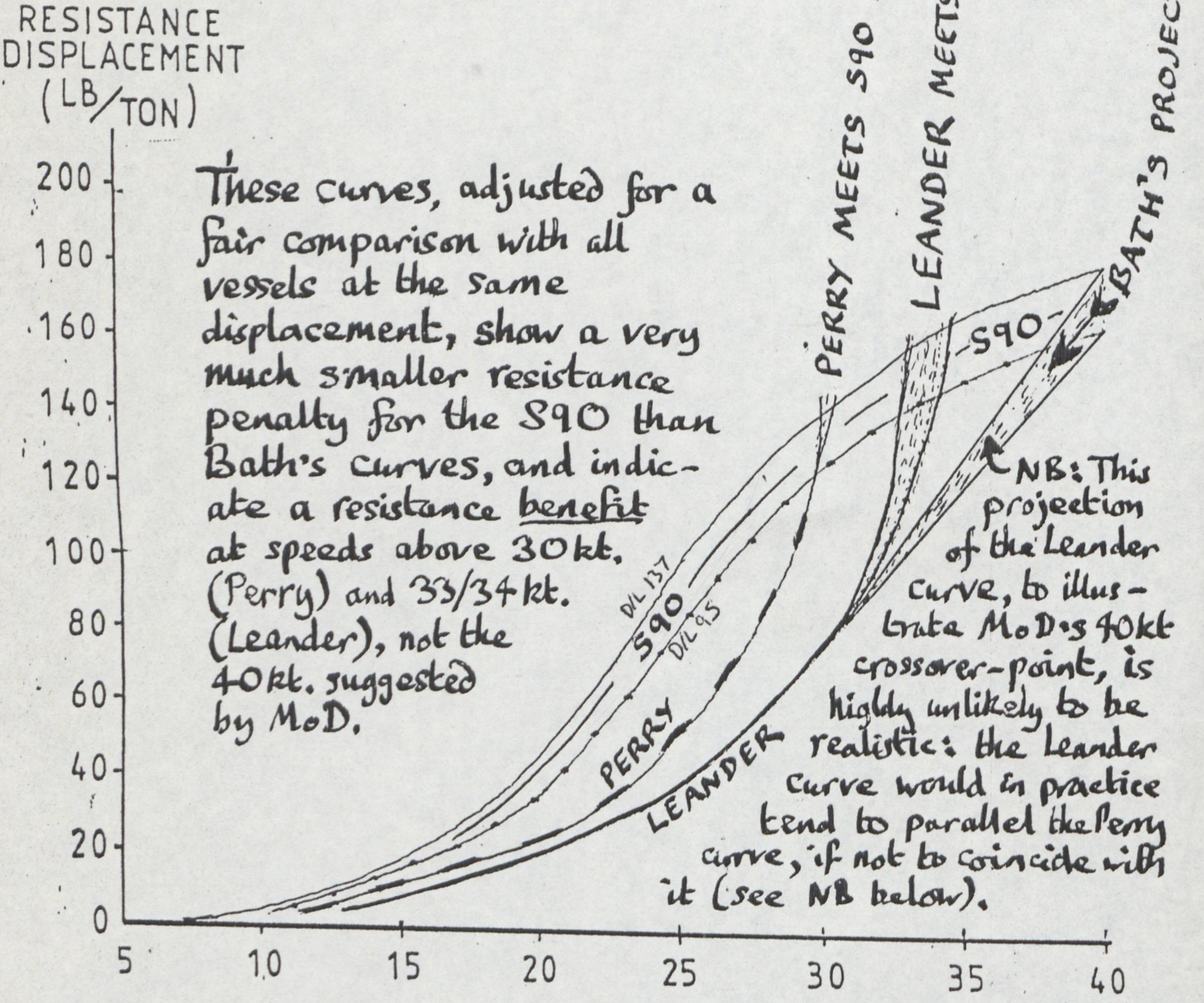
PERRY : D/L 54 : Δ2560T : L 362 FT
LEANDER : D/L 56 : Δ2560T : L 356 FT
S90 : DL 137 : Δ2560T : L 265 FT

CONFIDENTIAL

PERRY MEETS S90 AT 29~30 KNOTS

LEANDER MEETS S90 AT 33~34 KNOTS

BATH'S PROJECTION: 40 KNOT CROSSOVE



These curves, adjusted for a fair comparison with all vessels at the same displacement, show a very much smaller resistance penalty for the S90 than Bath's curves, and indicate a resistance benefit at speeds above 30kt. (Perry) and 33/34kt. (Leander), not the 40kt. suggested by MoD.

NB: This projection of the Leander curve, to illustrate MoD's 40kt crossover-point, is highly unlikely to be realistic: the Leander curve would in practice tend to parallel the Perry curve, if not to coincide with it (see NB below).

FIGURE 2 - COMPARISON OF HULL RESISTANCE
(DERIVED FROM FIGURE 1 TO A BASE OF SPEED)
(ALL VESSELS ADJUSTED TO LEANDER TONNAGE)

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NB: The Leander curve is based on the suspect Fig. 16 of Adml. Bryson's paper. We are advised that the correct curve is very much closer to

HULL FORMS FOR WARSHIPS

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FLAG ITEM

HULL FORMS FOR WARSHIPS

Introduction: the problem

The Government may come under strong public criticism in Spring 1987, when the 45-day trial of British Shipbuilders in a civil action brought by the inventors of a new form of warship hull begins in the High Court. The story of the short/fat ship, which will emerge as the trial unfolds in the run-up to the next Election, will be presented in the media - rightly or not - as a tale of Ministerial inaction despite repeated pleas to successive Defence Ministers by the inventors for help against deceit, malice, theft and incompetence not only in British Shipbuilders but also at the highest levels in the Royal Navy.

Naval personnel may now be named in the court action. The DPP may have to intervene, since some of the defendants' actions are alleged to be criminal. It may be alleged, for example, that evidence has been falsified. The reputation of the Government, which, the inventors say, should have prevented its servants from taking unlawful actions, could be greatly damaged.

The inventors, Thornycroft, Giles & Associates (TGA), allege that British Shipbuilders stole their designs, tested them exhaustively and incorporated them in the Hong Kong Patrol Craft. The allegations are well supported and BS have already admitted unlawful testing of the design. But their defence is that the design is worthless and the Navy (which appears to have been implicated in the unlawful testing) is vigorously supporting that defence by its own rejection of the designs.

The opportunity

Though the Navy has formally rejected the new designs on the grounds that the hull could not perform as the inventors claim, the circumstances of that rejection appear to be improper and the reasons for it appear to be unsound.

If TGA are right, the Navy could have more, better, cheaper and very much faster ships than now. Worldwide orders could follow.

Lord Hill-Norton's Committee

In February 1985, Lord Hill-Norton, a former Chief of the Defence Staff, set up an unofficial committee to examine the Navy's rejection of the new design. Members are Lord Strathcona (former Minister of Defence Procurement); Prof. RV Jones (former scientific adviser to Churchill and author of "Most Secret War"; Dr. Richard Garwin (a defence/scientific adviser to the US Government); and Sir Terence Conran (Habitat: crew accommodation).

Lord Hill-Norton intends to present his report to the Prime Minister in February or March. It will probably recommend that an official committee of inquiry should re-examine the potential of the TGA design. The report will probably be published.

THE NEED FOR INVESTIGATION

The court case

It is urgent that the Ministry of Defence and the Department of Trade and Industry should satisfy themselves, by independent, impartial and thorough investigation, that the allegations which have been or may yet be made against individuals under their aegis are false. At present, the defendants named are officials of British Shipbuilders and its subsidiaries (DTI), but it is probable that at least one former official of the Sea Systems Controllerate at Bath (MoD) will be named in further pleadings. Ministers are involved only to the extent that TGA have repeatedly asked them for assistance and have not got the help and protection they wanted.

It is likely, however, that considerable publicity will be given to the case, and that Ministers may be strongly criticised for their alleged inaction. A full account of the matters alleged in the case is set out in this dossier. If the suggested investigation reveals that the allegations are, in substance, true, serious consideration should be given to the possibility that British Shipbuilders should be invited to settle the case out of court. In this way, whatever wrong has been done can be speedily righted without the damaging and hostile publicity which the hearing of the case would attract.

TGA's Sirius S90 design

This dossier also contains an account of the less than fortunate circumstances in which the Navy came to reject the TGA design and an assessment of the Navy's stated reasons for saying that the design will not be as cheap or effective as the inventors claim. It is not clear whether the design would work as the inventors say it will, though there is much good evidence to suggest that it would. What is clear is that both the manner of the Navy's rejection of the design and its substance are questionable.

British Shipbuilders' principal defence in the court action is that, although they admit that they stole the design and tested ~~them~~it extensively, the design is worthless and therefore only a token compensation of £100 should be made.

The possibility should be investigated that the Sea Systems Controllerate at Bath is maintaining its objections to the TGA design not so much because those objections are soundly based as because the objections support British Shipbuilders' case that the design is worthless. Is it further true that the Sea Systems Controllerate was itself involved in the unlawful testing and therefore has a direct interest in supporting British Shipbuilders' contention that the design is of no value?

It may also be worth asking independent naval architects to look at both sides of the case for the design. If they report favourably, MoD may think a proper test programme worthwhile.

WHAT ARE FRIGATES FOR?

Apart from the obvious point that if a wrong has been done it should be put right, does the question of the short/fat ship matter? This section of the dossier is designed to help the reader to understand what follows by giving on outline of what the debate is about and what the relative merits of conventional and short/fat frigates may be.

The submarine threat

As early as 1947, an important report by Professor R.V. Jones pointed out that no major surface fleet deployment could in future be made without thorough and effective air cover. This consideration is important in two respects: first, air cover is necessary not only to defend surface ships from air attack, but also to assist in the detection and destruction of submarines; secondly, surface ships are so vulnerable to attack either from the air or from beneath the sea that their role has, in recent years, diminished in importance while the role of submarines, less easy both to detect and to destroy, has correspondingly increased.

The Soviet Union is now believed to possess some 300 submarines, and is building a new submarine every month. Of these 300, it is thought that some 100 are deployed in the North Atlantic, the primary sphere of operations of the Royal Navy. One of the Navy's roles, in the event of war, would be the policing of the Greenland/Iceland gap and the detection and destruction of hostile submarines attempting to pass through it from the northern ports of the Soviet Union into the Atlantic. The best of these submarines are nuclear-powered, built to withstand operation at great depths and capable of speeds of up to 45 knots even at a depth of 5,000 feet.

Detection

The Soviet Union has, in recent years, come to appreciate the importance of noise attenuation in submarines to make detection more difficult. Modern towed-array sonars, such as the Type 2057, can detect submarines at ranges of 100 miles or more: hence quiet running has become essential to survival.

The first duty of an anti-submarine frigate, such as the conventional Type 23 Frigate or the unconventional Sirius S90, is to detect, classify and locate hostile submarines. The method now generally used is the towing by cable of an array of passive sonar listening devices at a distance of up to three miles behind the frigate, which must itself be very quiet-running so that its noise does not "deafen" its own sonar array, and so that it cannot itself be readily detected by the submarines it is trying to find. For speed, the frigate sprints to the point where the detection is to begin, then deploys its towed array and, for silence, drifts at the slowest practicable speed to give the listening devices the best chance of detecting hostile submarines. This is known as the "sprint-and-drift" mode.

Destruction

Once the towed array has detected a possible submarine contact, computers on board the frigate spend some 20 minutes processing the signal to remove extraneous noise and to confirm that the contact is, indeed, a submarine. Identification Friend or Foe (IFF) procedures are used to rule out friendly submarines, and the characteristic sound-signatures of Soviet and other non-Nato submarines, stored in the computer's memory, are matched with the signal, allowing identification not only of the class but also, in many cases, of the individual submarine.

Particularly at extreme range (50-100 miles), the towed array cannot pinpoint the submarine exactly. Accordingly, a helicopter is detached from a platform at the stern of the frigate to drop a series of sonobuoys in the area indicated by the signals from the towed array. If the sonobuoys give a definite fix, the helicopter can then launch a torpedo to destroy the submarine before returning to its platform aboard the frigate.

Other roles

The Royal Navy's frigates are primarily for anti-submarine warfare. As a consequence of this role, they must be able to defend themselves against the submarines they are hunting. Soviet submarines are equipped with fast, intelligent and powerful heavyweight torpedoes: and, by communicating with their land-bases or aircraft-carriers through Extra-Low-Frequency (ELF) radio transmission, they can call up aircraft to destroy any frigate which is beyond their own range. Hence the Royal Navy's frigates must be capable of defending themselves against both aerial and submarine attack, as well as against missiles launched by the enemy's surface ships.

This *defensive* capability can be used not only in protecting the frigate itself but also in protecting other, less well-protected surface ships. Both the speed and the defensive capability of frigates make them useful as ocean-going escort and support vessels, a role which they fulfilled in the Falklands campaign.

The noise attenuation and radar-image minimisation which are necessary features for anti-submarine frigates make them suitable for missions where concealment is essential.

Frigates also have an anti-ship *offensive* capability. The intelligent, sea-skimming missile, which ~~were~~ was devastatingly effective against British warships in the Falklands, is the primary punch of a modern frigate. Over-the-horizon targeting greatly helps long-range attack.

The Type 23 Frigate

The Type 23 Frigate began life in the Spring of 1981 as an Outline Staff Target based on earlier concept studies for a light Anti-Submarine Warfare (ASW) Frigate. The essential features were a quiet platform; high endurance at moderate towing-speeds; a flight-deck and logistical support for an EH101 medium helicopter; hull and superstructure configured to minimise radar echoing area (REA); a length of 100m; a displacement of 2,500 tonnes; and a unit production cost ceiling of £70m at September 1980 prices (£98m at September 1985 prices).

Since then the specification has undergone numerous changes. Additional general-purpose capability was added to give the ship export potential; a helicopter hangar was added and the flight-deck lengthened by 3 metres; a second Sea-Wolf missile launcher (vertical) was added; further additions to length were made to reduce congestion in the machinery spaces; damage control and interior design were modified in the light of the Falklands experience (superstructure was too lightweight to resist even machine-gun bullets, and caught fire too easily both because its magnesium alloy was flammable and because bulkhead-linings in earlier frigates produced dense smoke); the length was increased to 123m (for the extraordinary reason that this is the greatest length which can be accommodated in the frigate-dock at Devonport); the displacement rose to 3,850 tonnes; and the cost, at September 1985 prices, probably approaches £200m for a fully-equipped ship, including £24m for the helicopter alone.

At this very high price, it is unlikely that many Type 23 Frigates can be built without grave strain upon the Naval budget. And it is doubtful whether the very long procurement timescale for the Type 23 (of which not a single vessel has yet been built, though one is now building) is satisfactory.

However, the main concern is more fundamental. Can the Type 23, all £200m-worth of it, actually do the job for which it was intended? Can it destroy enemy submarines? There is some reason to doubt whether it can.

The reasons for doubt are twofold. First, the designed maximum speed of the Type 23 is only 28-29 knots, which is not only 9-10 knots slower than the best speed of Soviet destroyers of the Kashin and Kotlin classes but 17-18 knots slower than the present generation of Soviet submarines.

The relatively slow speed of the Type 23, which is actually below the maximum speed of some World War II destroyers, greatly reduces its effectiveness in detecting enemy submarines, because two separate bearings have to be taken in order to determine which of the two positions indicated by the towed array is the actual position and which is its mirror-image: hence the ship needs great speed to be able to sprint to a new position. An alternative, of course, would be to use two ships hunting simultaneously, but at £200m per ship this option is unlikely to be available as often as is desirable.

Secondly, the anti-submarine firepower of the Type 23 may be inadequate. The problem arises because the Type 23 is so slow that it can outrun neither an enemy submarine nor a Soviet heavyweight torpedo, which can run at 50 knots. Hence the Type 23 has to keep well away from the submarine which it is hunting; and it must rely on its helicopter to deliver the missile intended to destroy the submarine.

However, the helicopter also has to carry enough heavy sonobuoys to pinpoint the position of the submarine after its general location has been indicated by the distant towed-array sonar. The weight of the necessary sonobuoys is so great that the helicopter can carry only one lightweight Stingray torpedo. If that torpedo misses its target (and its maximum speed at depth is only 30 knots for a very limited distance), there is no second chance. Furthermore, it is doubtful whether the torpedo, which has to be lightweight because the helicopter would be unable to lift a heavyweight version, packs enough punch to do much damage to the strongly-reinforced double-hulls of the latest generation of Soviet nuclear submarines (though the Stingray may prove effective against conventional submarines of an earlier generation). There are strong doubts about the capacity of the Stingray either to run or to do damage at depth: it is only effective in shallow water.

In any event, helicopters (and hence the torpedoes they carry) cannot be launched in high sea states; and limited fuel capacity constrains them to a very limited duration on station when carrying heavy sonobuoys or dunking-sonars.

Therefore a) the very high unit cost of the fully-equipped Type 23 makes it unlikely that many will be built (and the price could be like a magnet to the enemy, who will do all they can to destroy so expensive and rare a vessel); and b) the Type 23, although very expensive, may be unable to fulfil its primary, anti-submarine role effectively, if at all.

The Sirius S90

The Sirius S90 frigate concept was first formally submitted to the Ministry of Defence on 21 May 1982, when Thornycroft, Giles & Associates and British Aerospace Dynamics Group presented "A Private Proposal for the Type 23 Frigate" to Admiral Sir Lindsay Bryson, then Controller of the Navy.

Just over a year later, on 8 July 1983, the Hull Committee of the Defence Scientific Advisory Council decisively rejected the S90 concept. The Hull Committee's report concluded with these words:

"Finally, we must state our opinion that the short-wide hull form of the S90 design has such fundamental drawbacks as a concept for a modern class of frigate that no amount of further testing or detailed designing is likely to affect our conclusions in any important respect. We are not, of course, concerned with the value of the hull form for patrol boats and other small craft."

The circumstances of the Hull Committee's outright rejection of the S90 concept, and the technical and financial arguments it put forward, are suspect, and are themselves worthy of careful investigation. At this point, however, the discussion will be confined to a consideration of the major differences between the S90 and the Type 23.

The ship proposed by Thornycroft, Giles as an inexpensive stalking-horse for the Type 23 was a 90-metre, broad-beamed vessel of 2,800 tonnes displacement (at that time the Type 23 was to have been 2,800 tonnes; this was later increased to 3,850 tonnes).

The chief claims of Thornycroft, Giles for the S90 design were that the very low length-beam ratio (i.e. the shortness and fatness) of the S90 design made the ship cheaper to build, to outfit and to refit than the Type 23, and gave it greater reserve stability, less susceptibility to longitudinal stress (which has adversely affected the long/thin Type 22 and stretched Type 42 destroyers), better seakeeping and, above all, the possibility of very much higher maximum speed. Against these advantages, the most significant disadvantage was that the short/fat S90 would need more power and hence more fuel to achieve a given speed at a given displacement than the traditional, long/thin Type 23.

However, Thornycroft, Giles claimed that the hull of the S90 was so designed that, particularly at high speed, high pressure and hence hydrodynamic lift was generated under the ship, overcoming to a surprising extent the resistance penalty otherwise inherent in the short/fat form. Thornycroft, Giles also claimed that the effect of hydrodynamic lift was so effective in reducing resistance that the relatively small extra requirement for power and fuel in the S90 would be more than outweighed by the savings in the costs of original construction and outfitting, through-life maintenance and occasional major refits.

In short, Thornycroft, Giles claimed that their design could give the Navy either the same frigate at less cost than the Type 23 or a faster, better frigate at the same cost.

The validity of these remarkable claims is considered elsewhere. If they are true, however, they hold out the opportunity of making good the serious deficiencies in the effectiveness of the Type 23 Frigate which are set out above.

Recent tank-tests at BHC indicate that the maximum practicable speed of a 97-metre, 3,600-tonne Sirius hull-form (admittedly with considerably greater installed horsepower than the Type 23) is well above 45 knots. The installed power would be 150,000 BHP, the same as that in the fastest Soviet dstroyers; but the maximum speed of the 97-metre Sirius would be 48-50 knots, against only 37-38 knots for the Soviet vessels. If the Sirius, even with extra power, can achieve such speeds at no greater cost than the 28-knot Type 23, the advantages are clear.

A 50-knot Sirius frigate could chase and catch Soviet surface ships and submarines. Therefore, though the Sirius might still use a helicopter to deliver sonobuoys or dunking-sonars for final pinpointing of an enemy submarine, it need no longer depend on the helicopter for delivery of a lightweight and probably ineffective torpedo: instead, it could itself travel fast enough to approach the submarine and despatch a ship-launched heavyweight torpedo with a warhead powerful enough to destroy the submarine with certainty.

Of course, the submarine would undoubtedly hear the Sirius approaching: but it would then face the choice of calling up aircraft to attack the Sirius (but this would severely limit the submarine's freedom of manoeuvre, since it would have to be closely supported by aircraft-carriers, or would have to confine its movements to waters close to its own airfields); or of launching a heavyweight torpedo against the Sirius (which it could outrun); or of running away (but the Sirius could run faster and catch it).

The speed of the Sirius could even render a helicopter unnecessary altogether, by the integration of search and attack capacity in one vehicle - the ship itself. The Sirius can move fast enough to dispense with a towed array and to lay two untowed line-arrays of complex passive or active sonobuoys instead, giving a definite fix on hostile submarines at a reasonable range. The ship could then give chase, using its own bow-sonar for final pinpointing before launching its heavyweight torpedo to knock the submarine out.

Dispensing with the £24m helicopter would yield an immediate 12-15% saving on the total initial cost of each ship, with savings to match on through-life running costs. Further savings, and increases in speed for a given power, could be achieved by making the Sirius smaller than the Type 23, which is possible if the helicopter flight-deck and hangar are dispensed with.

The latest series of BHC tests have established that a 2,000-tonne, 75-metre Sirius (only 500 tonnes smaller than the original design for the Type 23) would be able to reach speeds of 50 knots with only 96,500 BHP. The cost of the Sirius S75 would, of course, be very much less than that of the Type 23, allowing many more to be built for the same money and greatly increasing the effectiveness of the Royal Navy's anti-submarine warfare role.

HOW THE NAVY REJECTED THE S90 CONCEPT

The circumstances of the Navy's rejection of the S90 concept do not appear to be satisfactory. The reasons why the Navy acted in the manner set out below need to be investigated:

21 May 1982: At the request of Mr. Geoffrey Pattie, then Parliamentary Under-Secretary of State for Defence Procurement, Thornycroft, Giles and their partners in the S90 project submitted their "Private Proposal for the Type 23 Frigate" to the MoD.

14 July 1982: Mr. Pattie called a meeting at which TGA, British Aerospace Dynamics Group and Frederikshavn Vaerft Shipyard of

Denmark were invited to conduct a validation programme in accordance with the recommendations made in the original proposal. These recommendations had previously been accepted by the Maritime Technology Committee of the Department of Industry, which had, in March 1982, provisionally agreed a research grant of £47,500 towards the £237,500 cost of the evaluation.

10 March 1983: While the validation programme was still in progress, Mr. David Giles of Thornycroft, Giles gave a paper on "The Design Philosophy of the S90" to the Hull Committee of the Defence Scientific Advisory Council, at the Committee's request. He emphasised that the major part of the S90 validation programme was still to be completed, and his paper was therefore confined to general design issues rather than to specific details. Mr. Giles, who had been asked to submit his text 3-4 weeks in advance of the meeting, had pointed out that "the disadvantage, when work is still in progress, is that the text might be incomplete and it might then be necessary to issue an addendum". The DSAC never requested such an addendum, even though Mr. Giles' text made frequent mention of the fact that the validation programme would be complete at the end of May; and at no point did they inform him that they were about to produce a report on his designs.

20 May 1983: Following completion of all the major tank-tests of the S90 at the NMI and BHC tanks, the results were summarised in a 250-page validation report and given to the Controller of the Navy, who circulated it to Ship Department, Bath (now the Sea Systems Controllerate), to YARD Ltd., who had been contracted by MoD to produce a comparison design for the Type 23, and to the DSAC Hull Committee.

8 July 1983: The Hull Committee submitted its report to the Minister. It is clear from the contents of the report that, although the Hull Committee had available to it the summary validation report, it failed to use the up-to-date data in that report and relied solely upon the incomplete data supplied by Mr. Giles in his paper of 10 March.

It is also evident from the report that the Hull Committee made adverse comments on matters about which Mr. Pattie had not asked Thornycroft, Giles for information. The validation programme, as agreed at the meeting between Mr. Pattie and the backers of S90 in May 1982, was to include only the following matters:

* Development of a design using two lines-plans and two 1/38.25-scale models run against the existing Osprey model as a geosim, for initial resistance tests;

* Hydrostatic calculations, propeller design and more detailed design based on the final lines-plan;

* Construction of a final 1/20-scale tank-model using the final lines-plan, and testing of the model for initial resistance and propulsion characteristics in calm water;

* Construction of a 1/10-scale self-propelled model for seakeeping tests in open water, and refurbishment and re-equipment of an existing 1/10-scale 'Leander' conventional frigate model for seakeeping comparisons;

* Seakeeping comparisons with the 'Leander' 1/10-scale model to be run in open water with wave-specrta scaled to approximate with those of the AMTE 'Two Frigates' report, and at comparable speed and displacements;

* The tank-model to be run in controlled conditions comparable to the open-water experiments, for possible correlation of full-scale, controlled, open-water model experiments and comparative data for the two hull-forms;

* Correlation of all data and the compiling of reports.

The exercise which MoD had asked Thornycroft, Giles to carry out was concerned only with the performance and seakeeping of the Sirius hull-form. It is, therefore, surprising that the DSAC Hull Committee's report should have passed critical comment on the failure of the Thornycroft, Giles paper to take proper account of such matters as weapons-fit, noise attenuation, the need for clean conditions, the impact of nuclear, chemical and biological defences on systems and equipments, vulnerability to fire and smoke, and the need to apply shock standards.

Thus the Report of the Hull Committee of the Defence Scientific Advisory Council on the Sirius S90 concept was produced without the prior knowledge of the designers, so that they had no opportunity to make representations before it was sent to Ministers; it was produced on the basis of data which the Hull Committee knew to be incomplete and outdated, even though a summary validation report containing full and up-to-date information from tank-tests had been made available to it; and it was critical of matters upon which the designers had not been asked to supply information. Why?

The OPV III competition

TGA claim that the rejection of their designs for the OPV III offshore patrol vessel contract was also improper. This suggestion has not been investigated in detail, because the Government has decided not to proceed with the OPV III at all. However, TGA say, first, that they were not told that the displacement was to be between 1,250 and 1,750 tonnes, while their competitors were told; and secondly, that, before the Government scrapped the project, they were told that their design had been rejected because it was worse value for money than the rival design from Hall Russell, yet they have now learned that their 2,500-tonne ship, at £33m, was cheaper than the £35m cost of the much smaller 1,750-tonne rival. How, then, was the Hall Russell ship held to be better value for money? Was the decision genuinely fair? Or was it coloured by innate hostility to the TGA design?

BREACH OF COPYRIGHT IN THE OSPREY DESIGNS

British Shipbuilders have admitted breach of the coyright of Osprey Ltd. in its designs, but have said that the designs are worthless and have offered only £100 in compensation. The designers have started court proceedings and have won every round so far. The full trial, set down for 45 days at the request of British Shipbuilders, will take place in January 1987 before Mr. Justice Whitford in the High Court. A chronology of the events which are alleged, indicating that the Navy as well as British Shipbuilders were implicated in the unlawful testing of the designs and in their incorporation into the Hong Kong Patrol Craft without permission of or payment to the inventors, is set out below:

1978: It became known that the Hong Kong Government wanted to buy five patrol craft to replace existing vessels. The Procurement Executive in London were put in charge of the contract.

1978/9: Thornycroft Giles suggested to the Procurement Executive that their Osprey short/fat ship might be a suitable design for the Hong Kong Patrol Craft and other naval vessels.

29 May 1980: David Giles of Thornycroft Giles visited the Vickers testing-tank at St. Albans. He met Mr. David Moor, the superintendent of the tank, who was most affable and offered to do a full design appraisal of the Osprey design. He asked to see a copy of the Osprey lines-plan and Mr. Giles said he would agree to that if his fellow-directors gave permission. A further constructive meeting took place on 16 June.

20 June 1980: Having obtained permission from the directors, Mr. Giles took the Osprey lines-plan to Mr. Moor at St. Albans and showed it to him. Mr. Moor asked if he could take a copy and was told that that would not be possible. He then asked if the copy could be left with him for a day or two, for inspection by other people at the tank. Mr. Giles agreed after asking for and getting a written undertaking of confidentiality.

27 June 1980: Mr. Moor wrote to Mr. Giles returning the lines-plan and saying that he had "not seen in it any feature which warrants any further special investigation at this stage".

August 1980: The Procurement Executive issued tender documents for the Hong Kong Patrol Craft (HKPC). The tender specified a length of about 60 metres, a displacement of 600-700 tonnes, a service speed above 25 knots and two heavy-duty marine diesels of 7200 horsepower each.

23 October 1980: Mr. Jack Daniel of British Shipbuilders, who had unsuccessfully been trying to design a jull-form capable of meeting the stringent specifications of the contract, asked his personal assistant, Mr. R. Mandeville, for "views on whether the Osprey design could be adopted (sic) to meet the HKPC Naval Staff Requirement and still be considered to be Osprey".

Mid-November 1980: Mr. Daniel gave instructions to Mr. David Moor for the building and testing of a model of the Osprey patrol craft, without the knowledge or permission of the inventors.

Friday, 21 November, 1980: An entry in the diary of Mr. Daniel mentions an "Osprey meeting at Bath". The entry has been crossed out and the words "Did not take place owing to non-availability of KJR" (Kenneth Rawson, then Chief Naval Architect and Deputy Director, Ship Design) added.

Monday, 24 November, 1980: Mr. Mandeville, Mr. Daniel's personal assistant, wrote to Mr. Rawson as follows: "At our meeting on Friday you said you required certain information ... " This letter, taken with the diary entry, indicates a) that the meeting did take place; b) that Bath were interested in TGA's designs; c) that Mr. Daniel was anxious to keep Bath's involvement secret.

December 1980: The Hall Russell shipyard, which had tendered for the HKPC contract, engaged Vickers Shipbuilding and Engineering Ltd., a subsidiary of British Shipbuilders, to design a suitable hull form. Mr. Moor had overall supervision of the project, though he had no previous experience of designing such a hull.

11 December 1980: Mr. Daniel told Mr. Moor to speed up the building and testing of the Osprey model, and repeated this instruction, emphasising urgency, on 12 December.

Mid-December 1980: Mr. Moor told Vickers' Ship Model Experiment Tank Division at Dumbarton to build a model of the Osprey from the lines-plan and four models of the Azteca, an earlier and smaller version of the short/fat ship. The Osprey model was no. 2219 and the four Azteca models were numbered 2208, 2209, 2210 and 2217. Later Mr. Moor told Dumbarton to build a further Osprey model from the lines-plan. This model was numbered 2225.

Late December 1980: Vickers began designing and building model hull-forms for the Hall Russell HKPC, as follows: Model 2224, drawn 22 December and built 24 December to 12 January; Model 2226 drawn 18 January 1981 and built 21 January to 31 January; Model 2230 built 30 January to 2 February. These models were based not on designs supplied by Hall Russell but from Vickers' own experience. Models 2224 and 2230 were derived from the Type 10 destroyer-form and Model 2226 was derived from an unrelated design of 1976. None of these designs was found able to meet the stringent specification for the HKPC. Design no. 2226 was forthwith abandoned. The other two models, based on the T10 destroyer form, would have been unable to meet the 25-knot speed requirement, since the T10 was intended only for a maximum speed of 21 knots if built within the other tender requirements.

January 1981: Dumbarton delivered the six Osprey and Azteca models to Vickers at St. Albans, where extensive tank-tests were carried out at the same time as the tests on the HKPC hull-forms. From the test results, plus full-scale trials data for the Osprey craft "Havornen", British Shipbuilders would have known that an enlarged Osprey was capable of meeting the tender requirements for the HKPC.

11 February 1981: Mr. Daniel visited St. Albans to watch a tank-test on the Osprey model run at a simulated 30 knots. He paid no other visits to St. Albans during the testing of the Osprey and HKPC designs.

16 February 1981: Mr. M. Stephens of BHC telephoned Mr. Giles to remonstrate that "you are running the 1/10-scale Osprey model at the Vickers St. Albans tank without our knowledge". BHC were at that time conducting tests for TGA on the design. Mr. Giles replied that his 1/10 model of the Osprey was in its shed at Bembridge. Mr. Stevens insisted that a large Osprey model was being run at St. Albans. Mr. Giles told him that this was certainly being done without the knowledge of Osprey Ltd.

24 February 1981: Mr. Giles had a meeting with Dr. A. Morrall of the Nautics Branch of NMI, who had also been testing Osprey models on behalf of TGA. Mr. Morrall confirmed that St. Albans were running the large Osprey model and said that, at the same time, they were testing an HKPC design for Hall Russell in accordance with their contract of December 1980. Mr. Giles said he thought the design work was supposed to have been finished by 4 November 1980. Dr. Morrall insisted that the model was for the HKPC and that it was still too slow to meet the stringent NSR. Mr. Giles decided that the best plan would be to let it be known discreetly in British Shipbuilders circles that he knew of the St. Albans tests of his design, in the hope that they would voluntarily confess to him what they had done, rather than making accusations which might result in their destroying all the evidence. He spoke to Mr. Graham Day of the University of Nova Scotia, who was due to visit St. Albans in the near future, and hinted that St. Albans were testing the Osprey model.

27 February 1981: Mr. Rawson told Mr. Giles that there was still a possibility of persuading the Procurement Executive to consider a tender with the Osprey design. This indicates that the design for the HKPC was at this stage far from complete.

13 March 1981: Mr. Martin Court, an employee of the Navy's Haslar testing-tank, visited St. Albans. At that time, the only tests being done at St. Albans were those on the Osprey models and on the HKPC.

20 March 1981: Vickers produced a report on the tests of model no. 2219, entitled "A design for a twin-screw patrol-boat". The document did not mention that the design was owned by Osprey Ltd.

March 1981: Vickers/BS produced a comparison of the performance qualities of the T10 hull-form and the Osprey form.

26 March 1981: Mr. Rawson, Chief Naval Architect and Deputy Director (Ship Design) at Bath, told BS that Mr. Giles had found out that the Osprey tests were being conducted.

27 March 1981: Mr. Daniel wrote to Mr. Giles confessing to the St. Albans Osprey model tests. Osprey Ltd. decided to take legal action.

3 April 1981: Osprey Ltd. issued a writ in the High Court alleging breach of copyright by British Shipbuilders. In correspondence and meetings up to the end of June, Osprey Ltd. complained of the building and testing of the Osprey model and sought undertakings that it should not be repeated. Legal advisers to BS said the building and testing had been done with Mr. Giles' implied permission merely for evaluating its claims for its performance. In these exchanges BS led Osprey Ltd. to believe that only one Osprey model (no. 2219) had been built, and concealed the existence of Osprey model no. 2225 and of the four Azteca models.

8 April 1981: Mr. Thornycroft and Mr. Giles visited the St. Albans test-tank to inspect the Osprey model.

Thursday 9 April 1981: Notwithstanding the writ, Mr. Moor gave instructions for further extensive tank-tests of Osprey no. 2225 as a matter of extreme urgency.

Friday 10 April 1981: Mr. Kenneth Rawson, Deputy Director (Ship Design) at Ship Department, Bath, wrote to Mr. Giles saying that his Department still had further studies to complete before being able to decide whether the Osprey design was feasible for larger ships. At the same time, Dumbarton were testing the Osprey and Azteca models day and night and at weekends.

Saturday 11 April 1981: Mr. Rawson obtained some data from Dumbarton on the basis of which he drew a curve in his own hand, replicating an anomaly in the tonnage of the vessel. The graph he drew showed a resistance-curve for the Osprey at "373 tonnes". In fact, no test of the Osprey designs was ever done at this tonnage, either by BS or by BHC/NMI, some of whose results were lawfully available to Mr. Rawson. It seems that Mr. Rawson had been given the results of the "373 tons" test at Dumbarton over the telephone and had assumed that "373 tonnes" was intended. One key point on the graph can only be calculated by using the very low propulsive coefficient of .51 for the Osprey which was calculated at St. Albans. Later, a telex from British Shipbuilders apparently giving instructions for the order in which the tests were to be done implied that the "373 tons" test was not done until Tuesday 14 April. However, the carriage-log of the Dumbarton tank (a card fixed to the model under test, bearing its technical details and the date, and later filed for reference) shows that the 380 tonnes (or "373 tons") test was in fact done on Saturday 11 April. The telex may, therefore, have been a fabrication made in an attempt to conceal the fact that Mr. Rawson, and through him Bath, had received the data.

11-27 April: The tests ordered by Mr. Moor in contravention of the writ were carried out without the knowledge or consent of Osprey Ltd.

Monday 13 April 1981: Mr. Rawson wrote again to Mr. Giles, saying that the studies had now been completed and that the Osprey design would not perform as its designers claimed. He attached the graph of the "373 tonnes" resistance-curve which he had received from Dumbarton on the previous Saturday.

April 1981: Several documents relating to the Osprey tests were destroyed in "a bonfire at Bath", according to a senior former employee. British Shipbuilders were later found to have destroyed documents also. Throughout April, despite the writ, testing of an Osprey model continued at St. Albans. At this time, Mr. Giles approached Lord Trenchard, the Navy Minister, and asked for his assistance.

30 April 1981: At a meeting at St. Albans, Osprey Ltd. made it clear that they intended to proceed with the case. Mr. Daniel said that the design for the HKPC had been completed by 4 November 1981 and that the Osprey testing had, therefore, had nothing to do with it. The following day, although it is contempt of court to destroy evidence, Vickers, on Mr. Moor's orders, destroyed the Osprey model they had been testing.

6 May 1981: As a response to Lord Trenchard's request for an assurance that the HKPC had not been based on the Osprey designs, Mr. Daniel wrote to Mr. John Davies, Director of Contracts (Surface Ships), as follows: "It is a matter of record that it (i.e. the HKPC design) was finished by November 4 1981." However, Mr. Davies had written to Hall Russell, the builders of the HKPC, in February making it clear that he was aware that the HKPC was still being tested at that time and that the design had not even been started in 1980.

June 1981: The Government announced that Hall Russell had been awarded the contract to build five offshore patrol vessels for Hong Kong. Subsequent publication of design details showed that the design was similar to the enlarged Osprey in dimensions, displacement, performance and hull form.

3 July 1981: At a High Court hearing before Mr. Justice Nourse, Osprey ltd. were granted an injunction against BS restraining them from using any information obtained from the Osprey model tests in any design, of whatever size; and an Order for Discovery, an Order for a Speedy Trial, and costs.

July to September 1981: Further models, nos. 2254A, 2254B, 2255 and 2265, were tested, based on the Osprey designs, and a final hull form derived from them was submitted to Hall Russell for the "Peacock" Class of HKPC vessels, which was submitted to the Procurement Executive in February 1982. The vessesl were built and are now in service. Their speeds, well above tank-test predictions, are wholly incompatible with the T10 hull-form from which BS say they are derived, but wholly compatible with results for the Osprey. Although the hull-form of the Peacock Class ships is not an exact copy of the Osprey lines-plan, the Peacock hull-form has certain characteristics which are unique to the

Osprey Ltd. design, and it is capable of unusually high speed for its length, beam and displacement.

10 September 1981: Mr. Giles learned from the Editor of "Jane's Fighting Ships" that the design for the HKPC had been done at St. Albans by Mr. Moor, and that the design had not been completed.

21 October 1981: BS were ordered by the High Court to discover documents relating to their tests of the four Azteca models simultaneously with the Osprey documents.

18 February 1982: At St. Albans, Mr. Moor gave Mr. Giles an account of the provenance of the HKPC design, including lines-plans and models with design features which would generate hydrodynamic lift under the hull, an idea which TGA had incorporated into their Osprey and Azteca designs but which was rejected (and continues to be rejected) by the Navy.

16 June 1982: Admiral Sir Lindsay Bryson, who had succeeded Admiral Sir John Fieldhouse as Controller (Navy) the previous year, wrote to Sir John Charnley, Controller R&D Establishments & Research, as follows:

> "These contentions (Bath's views on the TGA/Osprey designs) have been based on standard methodical series for resistance and seakeeping trials conducted on the Osprey in model and full scale."

The only standard methodical series of tests ever done on the Osprey was the unlawful series using six models and 2,900 test runs at the BS Vickers tank at St. Albans. The Bryson letter indicates that knowledge of the tests reached a high level in the Navy.

5 November 1982: The Appeal Court granted an Anton Pillar order against BS following the apparent disclosure of a third Osprey model in the St. Albans tank log, later discovered to have been an incorrect entry, though the matter is still being investigated. The Master of the Rolls, Lord Donaldson, said that the conduct of BS had given the appearance of being "deceit piled upon deceit".

14 December 1982: The following exchange took place in a <u>Newsnight</u> interview:

> **Interviewer**: "But supposing, if I may interrupt you, that Mr. Giles and Mr. Thornycroft demonstrate with their tank tests that you are wrong, what then? Will you accept their results?"
>
> **Admiral Sir Henry Leach**: "No, because <u>tank tests have been done</u> and, I am sorry, they are not wrong. What Mr. Rawson has said is absolutely right. And there is nothing new, thee is nothing novel in this. It's rather like all sorts of exaggerated claims ... " (author's italics).

The significance of Admiral Sir Henry Leach's reference to tank tests is that the tests done lawfully for Osprey Ltd. and TGA by BHC and NMI showed that Mr. Rawson was probably wrong (the latest BHC tests have established the presence and effect of hydrodynamic lift beyond doubt); hence the only tests to which Admiral Sir Henry Leach can have been referring were the unlawful tests done by BS, with the knowledge of Bath, at Vickers' tank.

July 1983: Mr. Giles was given an oral report of the results of the sea-trials of the HKPC, which had, as he expected, proved to be two or three knots faster on trials than the tank-tests had predicted, exactly as had been the case with the Osprey and Azteca, from which Mr. Giles claims the design was derived. Subsequent inspection of the HKPC reveals a tell-tale feature below the waterline which, together with the broad beam, is a notable feature of the TGA/Osprey designs. Certain minor features, such as the keel, had been changed in what Mr. Giles claims was an attempt to disguise the provenance of the design. The absence of a skeg in the HKPC caused undue rolling at sea.

6 February 1984: A letter from Mr. Cocks of Dowty to Mr. Giles said: "There is no doubt that the Navy is very upset by the affair" (i.e. the case against BS). Why the Navy, if they had no involvement?

11 April 1984: Osprey Ltd. were granted a Consent order for fuirther Discovery and Inspection covering all aspects of the HKPC, the tank tests and the sea trials.

28 June 1985: Mr. Giles wrote to Admiral Sir John Fieldhouse, then First Sea Lord and now Chief of the Defence Staff, to ask for a meeting "in order to acquaint you with matters which have arisen within the Osprey versus British Shipbuilders litigation since our last meeting, at which you expressed concern about the possible involvement of the Navy." Mr. Giles says that at that meeting Admiral Fieldhouse had asked to be told if the case should prove to involve tne Navy.

2 July 1985: Admiral Fieldhouse replied to Mr. Giles as follows: "In the penultimate paragraph of your litigation with British Shipbuilders, you imply that I was worried about the 'possible involvement of the Royal Navy'. I firmly recall that you raised this possibility which I challenged, and specifically denied any knowledge of RN involvement. This remains the position and that is the limit of my concern."

September 1985: The full trial was finally set down for hearing before Mr. Justice Whitford in the High Court in January 1987. 45 days were set aside, at British Shipbuilders' request.

October 1985: The QC who had agreed to take on the case on behalf of Osprey Ltd. told his clients that, after a month's detailed examination of the evidence, he considered it likely that the Director of Public Prosecutions would have to intervene in the case.

6 November 1985: Two members of the Prime Minister's Policy Unit visited the Sea Systems Controllerate at Bath to discuss the reasons for the Navy's rejection of the S90 design for frigates. Without prompting, Bath twice said that they had had no knowledge of or connection with the unlawful testing of the Osprey designs, though they had perhaps received some of the results "on a personal basis". Mr. B.O. Wall, Chief Naval Architect, was asked what a "standard methodical series" was and replied that he thought the term was usually applied to a particular series of tests carried out on propeller-forms. Despite repeated questioning he was unwilling to come up with what an independent naval architect tells us is the correct definition: a standard methodical series is a series of hull-forms (more rarely of other forms), based on a single design, so that each model was altered in one dimension while the other dimensions remained constant, so that the effect of the changes could be tested.

15 November 1985: A full transcript of a shorthand note of the meeting at Bath was sent from the Policy Unit to the Sea Systems Controllerate for checking.

December 1985: The Sea Systems Controllerate at Bath sent a revised draft of the note of the meeting to the Policy Unit. In the revised note, both references to the possibility of Bath having received data from the unlawful tests had been removed; and the Chief Naval Architect's wrong definition of the phrase "standard methodical series" had been replaced by the correct definition. The only standard methodical series of tests ever done on the Osprey hull-form was done unlawfully by BS.

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It will be apparent from the above chronology that no concealment or cover-up is now possible, even if it were desirable: too much of the hard evidence to substantiate what appears above is in the hands of the plaintiffs. It is most urgent that a thorough-going internal investigation be held, to find out the truth. If the allegations are in substance true, then a grievous injustice has been done to Osprey Ltd. and we should do all we can to see that the wrong is quickly righted.

One obvious question arises: who paid for the unlawful tank tests? More than 2,900 test runs were done on six expensive, 16ft models. The total cost could be as high as £250,000. That sum is large enough to appear on somebody's accounts.

Was it the Navy who paid? The plaintiffs have been trying for some time to get a copy of a letter written by Kenneth Rawson to Mr. Daniel of British Shipbuilders in late 1980, in which, they think, the possibility of a contribution to the cost of the tests from the budget of the Controller (Navy) is mentioned. The letter is probably dated between 18 October and 18 November 1980, and its reference number is D/S/DDSD/.../80. The relevant file number is probably between 360 and 390. At least one copy of the letter is still in existence.

THE NAVY'S CASE AGAINST THE SHORT/FAT HULL DESIGN

Until a full-scale, 90-metre prototype of the new design is built, there can be no certainty about the inventors' claims for price and performance. But it is already clear that a 55-metre version of the vessel (the Osprey class, now in service with the Danish Navy) is performing better than tank-tests had predicted.

Furthermore, recent testing at BHC and projections at the Swedish firm of KaMeWa on behalf of a consortium which hopes to use the design in an attempt to break the Blue Riband record for a trans-atlantic crossing by using a 60-metre short/fat ship have indicated that, if water-jet propellers and sufficient power are installed, the 90-metre version of the design could achieve a maximum speed approaching 60 knots, or twice the current maximum speed of British warships. with a surprisingly low powering and fuel-cost penalty.

The Navy's reasons why the design should not be adopted for full-size frigates are set out in the DSAC report, in Admiral Bryson's RINA paper and in a note of a meeting last November between the Ship Department at Bath and two members of the Policy Unit.

MoD's position can be summarised as follows:

The Minister for Defence Procurement had asked TGA to produce proposals which could be evaluated against the Naval Staff Requirement for the Type 23 Frigate to see if the new design offered advantages. DSAC, Y-ARD and MoD had each assessed the outline produced by TGA and had concluded that the S90 design failed to meet MoD's requirements because it would be too small to contain the weapons needed; would be too short to prevent electronic interference between weapons systems; would be under-powered for the specified speed; would have too little fuel endurance; would be too noisy to allow towed arrays to work; would roll too rapidly; would not survive damage adequately; and would not be cheap enough to compensate for these disadvantages.

The differences between the Navy's position and the results of our own inquiries are set out in the rest of this section.

The cost of the Type 23 and the Sirius S90

In discussion with Policy Unit representatives, MoD officials at Bath said that the S90 hull-form was cheaper to build than the conventional, long/thin form, but that the potential savings were only in "single-figure millions". They said that the Type 23 Frigate would cost £110m at 1984/5 prices (£118m at 1985/86 prices) with £30m (£32m) more for missiles, stores and supplies, including £10m (£11m) for a helicopter, making £140m (£150m).

Jane's "Fighting Ships", however, which correctly mentions the original target unit production cost of £67m at 1980 prices, estimates the present cost of the fully-equipped Type 23 at £200m, or £50m more than Bath's figure.

The Naval Staff Requirement for the Type 23 (No. 7609: Operational Requirements Committee) sets out the costs of the original concept at September 1980 prices:

Unit production cost for a 15-metre, 2,700-tonne Type 23 Frigate including a) diesel-electric propulsion and noise reduction; b) one Spey gas turbine driving two shafts with electric motors; c) accommodation for 165 men; d) limited NCBD; e) fuel endurance for 6,500 nautical miles at 16 knots; f) Type 2031 towed-array passive anti-submarine sonar; g) command, control, navigation and type 1006 radar; h) electronic counter-measures; j) surveillance radar; k) sonar Type 183 decoy: £62.9m

Add: active sonar £2.5m; magnetic torpedo-launcher £0.4m; lightweight Sea Wolf launcher £3.4m; ESM Canews £1.2m; Harpoon MM40 £1.6m; over-the-horizon targeting £0.3m; two small-calibre guns £0.4m; second Spey gas turbine £2.5m; second optical sight £0.2m; second tracker for Sea Wolf £1.9m; additional ESM £1.0m; contingency £3m: total £18.4m: £81.3m

Between the T23 NSR and the present design, the following weapons have been added to the specification: two Goalkeeper 30mm short-range missile-launchers £3.0m; Mk VIII 4.5in gun £1.0m; second launcher (vertical) for Sea-Wolf £1.6m: total £8.6m: £89.9m

To accommodate the equipment added since the original NSR, the length of the T23 has been increased from 115m to 133m and the displacement has risen from 2,700 tonnes to 3,850 tonnes. The NSR breaks down the £62.9m hull and equipment price into platform costs of £50.5m and miscellaneou weapons £12.4m. Of the £50.5m, it is reasonable to assume that about half is attributable to the hull itself and to the cost of pipe-runs, etc., which would increase in proportion to the increase in displacement. Hence £25m x 1,150/2,700 = £10.6m: £100.5m

Bath have advised us that the cost breakdown is roughly as follows: hull 12%, outfitting and machinery 38%, weapons 60%. If this breakdown, which differs markedly from that in the NSR, is correct, assuming that, say, 17% of the £89.9m cost of ship and weapons before the increase in displacement is attributable to costs that would rise in proportion to the increase, £15.3m would have to be multiplied by 1,150/2,700: £6.5m: £96.4m

Between September 1980 and September 1985, RPI rose by 40.6%, giving a unit production cost of: £135.5m-£141.3m

This sum, which is likely to be on the conservative side, is £17m-£23m higher than the £110m (£118m at September 1985 prices) quoted to us by Bath.

In addition, Bath quoted £30m (£32m at September 1985 prices) for missiles, stores, fuel and other consumable, including a helicopter, which they priced at £10m (£11m at September 1985 prices). However, NSR 6646, the specification for the EH101 helicopter, states that, at September 1981 prices, 50 helicopters would cost

£960m, which works out at £19.2m each, or £23.9m at September 1985 prices. This alone brings the cost of extras up to £43.9m, making the total unit cost: **£179.4m-£185.2m**

However, Bath have told us that the helicopter represents 46% of the £33m cost of stores carried on board. If that is true, then the total cost of stores carried on board, based on the known £23.9m cost of the helicopter, would be £52.0m, adding a further £8.1m to the total cost: **£187.5m-£193.3m**

The following table shows the difference between the figures quoted by Bath and those calculated above:

September 1985 prices	**SHIP**	**STORES ETC**	**TOTAL**
BATH	£118m	£32m	£150m
OUR CALCULATIONS	£136-141m	£44-52m	£179-193m
cf JANE'S	-	-	£200m

Bath suggested that a Sirius S90 of the same displacement as the Type 23 would cost between £90m and £98m, compared with the £110m they quoted us for the T23, a saving of between £13m and £22m at September 1985 prices. If our calculations are right, this saving would increase by a further £30-£50m, making the S90 considerably cheaper than the Type 23.

It seems desirable that like-for-like costings between the S90 design and the Type 23 should be done by MoD.

Hydrodynamic lift

TGA claim that their short/fat design overcomes the resistance penalty which would normally be expected of a broad-beamed vessel because certain peculiarities of the design induce high pressure and hence hydrodynamic lift under the hull, particularly at speed. Mr. Kenneth Rawson, then Chief Naval Architect at Bath, wrote to Mr. Giles on 13 April 1981:

> "Such dynamic advantage is confined to quite small craft and is lost at Osprey displacements - not surprisingly because displacement varies as the cube of the dimension and dynamic lift as the square."

In fact, the "square-cube law" is no barrier to the effect of lift on full-scale craft.

Bath commented that Mr. Rawson had "expressed himself badly": in fact, according to a naval architect and a leading scientist, he had made a bad error surprising for the author of a textbook on Froude's Law. The correct position is as follows:

Lift varies not only as the square of the length but also as the square of the speed. On 22 September 1981, after four exchanges of letters with Dr. Garwin, a scientific adviser to the US Government, Mr. Rawson wrote: "Like other dynamic forces, the lift coefficient will be the same for geosims at the same Froude number." This was, in effect, a reversal of Mr. Rawson's original position, though he did not explicitly say so.

The Froude number of a vessel of length L running at velocity V under gravity g is $V/\sqrt{gL}$, a variable which measures the influence of gravity on the vessel passing through the water. To make a realistic assessment of the likely performance of a full-scale, geometrically similar vessel (geosim) based on the measured performance of a 1/x-scale model, the model is run in the tank at a speed such that the Froude numbers of the model and of the full-scale geosim are the same.

The length of a 1/x-scale model of a vessel of length L is L/x: hence, to make the Froude number of the model, F_m, equal to that of the full-scale geosim, F_g, the model is run at a velocity of $V/\sqrt{x}$, which ensures that

$$F_m = \frac{V/\sqrt{x}}{\sqrt{gL/x}} = F_g = \frac{V}{\sqrt{gL}}.$$

For example, where $x = 25$, a 1/25-scale model will be run in the tank at $V/\sqrt{x} = V/5 = 1/5$ of the speed of the full-scale vessel.

Mr. Rawson had forgotten either that models in tank-tests are, for the above reason, run at a slower speed than their full-scale geosims; or that hydrodynamic lift varies not only in proportion to the square of the length but also in proportion to the square of the velocity; or both.

The following table shows the differences between Mr. Rawson's original statement and what occurs in reality:

	RAWSON'S LETTER			ACCEPTED POSITION		
	Vessel		Model	Vessel		Model
Length:	L		L/x	L		L/x
Velocity:	-		-	V		$V/\sqrt{x}$
Hydrodynamic lift:	L		$(L/x)^2$	L^2V^2		L^2V^2/x^3
Displacement:	L		$(L/x)^3$	L		$(L/x)^3$
Lift/Displacement:	1/L	<	x/L	V^2/L	=	V^2/L

Or, for example, where L=25, V=5 and x=25:

Length:	25		1	25		1
Velocity:	-		-	5		1
Hydrodynamic lift:	625		1	15625		1
Displacement:	15625		1	15626		1
Lift/Displacement:	1/25	<	1	1	=	1

Thus Mr. Rawson had assumed that, since lift varies as the square of the length while displacement varies as the cube (this is an example of what is called the "square-cube law"), the ratio of lift to displacement - and hence the effect of lift upon the hull

- would be less for the full-scale vessel than it had been for the model; while in reality the ratio of lift to displacement - and hence the effect of lift - will be the same for the full-scale vessel as it was for the model. This result is precisely what might be expected in geosims at the same Froude number, since hydrodynamic lift is a force which acts in direct opposition to the force of gravity.

Mr. Rawson was apparently unwilling to make explicit the fact that he had been wrong, and made no attempt to qualify the DSAC Hull Committee's statement, based on his error, that "a vessel of the size of the S90 will not gain any benefit from hydrodynamic lift at the operational speeds that are required". Though Bath now agree that the square-cube law is no barrier to the effects of lift on full-scale hull-forms, they do not accept that Mr. Rawson's original position was wrong, and that it influenced the DSAC's report rejecting the TGA design.

The presence of hydrodynamic lift under the hull of the S90 design has now been definitely confirmed by tank tests at BHC. Its effect in reducing drag and hence powering requirements at high speed, though not yet quantified with any precision, is considerable.

What factors determine the hull-form?

TGA now have tank-test measurements indicating that their Sirius S90 could, with sufficient power, travel at a maximum speed well over 60 knots, or more than twice the speed of the Type 23. This speed is not given as an operational requirement at present, because the Naval Staff believe that the powering penalty imposed at such speeds is too great. For conventional hull-forms, this view is correct. For short-fat hull-forms, however, the powering penalty is comparatively small, as recent tank-tests at BHC have demonstrated.

A speed of 60 knots and more would be useful to British warships tracking Soviet submarines, which can travel at speeds of up to 45 knots. Soviet destroyers of the Kashin and Kotlin classes can travel at 38 knots, almost half as fast again as the T23 (top speed 28-29 knots), but still very much slower than the S90.

Bath said that speed was not the major factor determining the uniquely long and thin hull design of frigates and destroyers. They said that other factors, such as the siting of electronic devices to avoid interference, and of weapons to give good arcs of fire, were important, and that speed, on the whole, was not.

A naval architect independent of Bath has told us that warships were long and thin "mainly because at the speed-length ratios at which warships have been operating to date, a narrow ship requires less power than a beamy ship. It is speed in relation to power. In my view, once you get over a certain speed-length ratio the judgement that a narrow vessel is the best answer is somewhat doubtful."

It seems clear that speed, rather than any other factor, is the dominant reason why destroyers and frigates are long and thin when almost all other ships are short and fat. In fact, Admiral Sir Lindsay Bryson, in his paper "The Procurement of a Warship" (RINA, 1984), lists speed as the first requirement to bear in mind when designing a hull:

> "Much effort was then spent getting the best hull form taking account of speed, seakeeping, endurance, machinery layout, REA and stability requirements..."

Is high speed useful or necessary?

Speed is the factor, above all others, which determines that the hull-form of a warship shall be long and thin, unlike other ships. But is the high speed of the S90 design either useful or necessary?

Bath said that the Naval Staff took the view, confirmed by history, that 28-29 knots was about the right speed. However, now that the submarines and destroyers of our potential enemies are very much faster through the water than their historical counterparts, this traditional view is no longer universally held.

Sidney Shapcott, formerly Deputy Director of the Admiralty Surface Weapons Establishment at Portsdown Hill, Director of Underwater Weapons at Portland and Director General of Air Weapons and Electronic Systems, said that speed was now of particular importance, particularly in bad weather, because bad weather affected submarines much less than it affected the surface ships which were trying to catch them.

"We ought to be looking at something in excess of the maximum speeds achieved by the other side. We would be living in a fool's paradise if we believed we could do anything with vessels that could not make that sort of speed. It is my firm belief tht we should be looking for something that can match that.

"Speed is very important, particularly because we can't provide the numbers of ships that other navies can provide. Since our numbers are obviously restricted, we should be looking for something that is very fast and can get where we need it quickly. It would have to be unconventional in some way or another."

Electronics and weapons

Bath said that the hull-form of a warship needed to be long because otherwise there would be interference between the different electronic weapon and detection systems. Captain Peter Prince, formerly in charge of electronic systems at MoD, says that any penalty caused by shorter length would be balanced by the advantage of broader beam, and that to suggest that ships had to be long for the sake of avoiding electronic interference was "nonsense".

Radars and electronic detection

Bath suggested that the arcs of coverage of radars and other electronic devices would be poorer on a short/fat ship. This view is not supported by the Y-ARD report on the S90 (July 1983: part V, section 1, para. 1): "The height of the mast and the technique of using a bandstand above the navigating bridge have enabled good operational arcs to be achieved for the Sirius and are likely to lead to detection ranges greater than those obtained by conventional frigates."

Resistance through the water

TGA claim that, although their hull form is more resistful than conventional forms because it is short and fat, the resistance penalty is not as great as might normally be expected and is offset by higher propulsive efficiency, perhaps helped in part by hydrodynamic lift; thus less power would be needed for a given speed than a broad-beamed ship would normally require, and very high speeds would be possible for a relatively small increase in installed horse-power.

Bath consider that the S90 hull form is up to twice as resistful as the Leander Class frigate, particularly at normal operational speeds. The basis for this conclusion is in the attached comparisons of hull resistance. Figure 1 was provided by TGA and was published in the proceedings of the 1984 RINA meeting to discuss Admiral Sir Lindsay Bryson's paper "The Procurement of a Warship". It is not disputed by Bath.

Figures 2 and 3 convert Figure 1 to allow the resistance and effective horsepower requirements of different hull forms to be compared at different speeds. Figure 3 suggests that, at 28 knots, the TGA design requires twice the effective horsepower (EHP) of the Leander and is two-thirds more resistful than the Type 23, the figures being as follows: Sirius S90 29,250 EHP, T23 17,000 EHP, Leander 14,000 EHP.

If Figure 2 is correct, the resistance penalty of the S90 against the US "Perry" Class frigate disappears at about 32 knots, which is above the operational range which the Naval Staff say is necessary. Though the Leander and Type 23 curves are not produced far enough to indicate the crossover-point with the S90 curve, Bath think that point would not be below 40 knots, at which point the S90 would begin to use less power than the T23 or the Leander.

However, there is considerable doubt about the accuracy of the resistance-curve for the Leander, which is based on figure 16 in Admiral Bryson's paper. A naval architect has suggested that the EHP scale on the left-hand side of the curve in Fig. 16 is incorrect. Though Bath maintained that the curve was correct because the maximum speed of the Leander was 30 knots and the propulsive coefficient was 0.6 (18,000 EHP divided by 30000 BHP, the installed horsepower), the actual maximum speed of the Leander is 28 knots, as marked on Admiral Bryson's Figure 16. This maximum speed has been confirmed by the former captain of a Leander class frigate, who achieved a best speed of 28.1 knots lightly loaded in ideal conditions on sea-trials immediately after a refit costing £80m. Hence Admiral Bryson's resistance curve for the Leander appears to be over-optimistic.

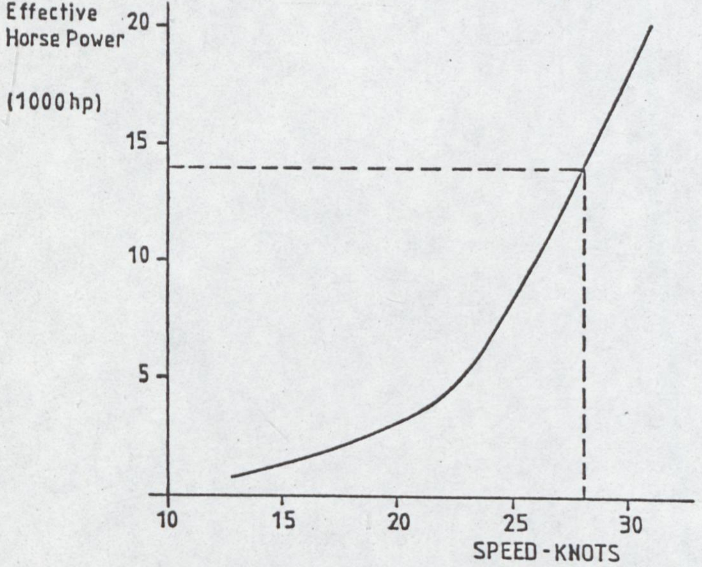

Fig. 16. EHP-Speed Curve for Leander Class Frigate at 2,600 tonnes

Even if Bryson's curve is accepted, it appears that the Leander curve based upon it has not been correctly extrapolated at its right-hand end in the replotting of Figure 13. The crossover-point with the S90 should occur at 33-34 knots, not 40. Similarly, the crossover-point for the Perry curve with the S90 would be 29-30 knots, not 32 knots.

Furthermore, if Admiral Bryson's Fig. 16 is wrong, the Leander and Type 23 curves should be broadly similar to the Perry Class frigate's curve, since curves for ships of similar form should not markedly differ. This gives a crossover-point not at 40 knots but at 30 knots or less, greatly reducing the estimated difference between the powering requirement of the S90 and of the Leander/T23. Of course, even if all the above corrections are made, the EHP of the S90 is substantially greater than that of its rivals in the normal operating speed-range, but tests at BHC indicate that the installed BHP and hence extra fuel cost would not be as great as the EHP figures suggest.

Besides, the S90 resistance-curve may be unduly pessimistic: it is based solely upon tank-tests, which have, in the past, been shwon to be conservative in their performance predictions for the TGA designs. These have an unusually low correlation factor (an adjustment to allow for differences between tank predictions and full-scale performance) of between 0.86 and 0.96, although Y-ARD Ltd. and Bath originally said that the correlation factor of the S90 form was 1.04. Now Bath accept that 0.9 is realistic, probably because the Hong Kong Patrol Craft, which incorporates many features of the TGA design, has a correlation factor of 0.86.

The correlation factor contributes to the propulsive coefficient, which in turn determines the amount of installed power which a full-scale ship will need. Y-ARD Ltd. estimate, on the basis not of tests but of computer predictions based on traditional hull-forms, that at 2,800 tonnes an S90 would require 59.5 MW of installed power. Tests done by NMI for Thornycroft, Giles indicate, however, that for a hull only 200 tonnes lighter only 35 MW would be required. Y-ARD's figure is 70% higher than NMI's. DSAC used the higher figure when rejecting the S90 concept.

The attached diagram illustrates the discrepancy. Bath have suggested that the discrepancy arises in part because the NMI figure relates to a clean, bare hull. In fact, as the diagram shows, the NMI figure includes an allowance for fouling, etc.

Bath consider that the actual powering requirement lies somewhere between the NMI figure and that of Y-ARD. TGA say NMI are right.

Fuel cost

If, as described above, less power is needed than theory based on traditional hull-forms suggests, less fuel will be needed than official estimates indicate. Thornycroft, Giles have estimated that the extra fuel cost for an S90 throughout its 20-year life would be £6m, which represents about 1.9% of total operating costs for a standard frigate.

Bath, however, said that the through-life cost of the extra fuel would be £10m to £20m, about 70% higher than the figure calculated by Thornycroft, Giles, The discrepancy is about the same as that between the Y-ARD and NMI estimates of powering requirement. If the extra fuel cost were this high, the cost savings on building and outfitting alone would outweigh it, with further savings on the cost of maintenance and refits.

Subsequently, Bath said that fuel represents about 10% of the predicted running-costs of a Type 23 frigate, or about £1m per annum at current prices. They estimated that the S90 could use up to twice the fuel of the Type 23. In a 20-year life-span, the through-life extra cost would thus be not £10-11m but £20m, or about twice Bath's original estimate and more than three times the Thornycroft, Giles estimate.

TGA have done some detailed, comparative calculations based on the typical operating profile of a frigate. These calculations are based upon an S97 TGA design at 3,600 tonnes and a T23 also at 3,600 tonnes, based on Rolls Royce estimates of time spent at different speeds in the operating range. The calculations assume that SM1A (T23) and SM1C (S97) Spey gas turbines will be used above 17 knots, at which speed they become efficient, and that Paxman Valenta diesel-electric engines will be used below 17 knots. Fuel is assumed to cost £200 per tonne, though the rapidly falling oil price would, of course, work to the advantage of the TGA designs.

ANNUAL FUEL CONSUMPTION OF S97 @ 3600 TONNES V. T23 @ 3600 TONNES BASED ON ROLLS ROYCE ESTIMATES OF TIME SPENT AT SPEED

SPEED (kt)	HOURS (pa)	TOTAL POWER (kW)		FUEL CONSUMPTION (kg/kWh)		(tonnes/hr)		(tonnes/yr)	
		T23	S97	T23	S97	T23	S97	T23	S97
28.0	90.0	28000	36000	0.236	0.225	6.610	8.810	595	729
26.0	201.6	21112	26185	0.247	0.237	5.215	6.206	1051	1251
22.5	342.0	10663	14696	0.285	0.285	3.040	4.115	1040	1407
19.5	583.0	5073	6637	0.285	0.280	1.446	1.859	843	1084
16.5	745.0	1865	1865	0.250	0.250	0.466	0.466	347	347
13.5	756.0	821	746	0.250	0.250	0.205	0.186	155	141
10.5	576.0	671	597	0.250	0.250	0.168	0.149	97	86
4.5	306.0	373	336	0.260	0.260	0.097	0.087	30	27
	3599.6	= 150 ship-days/yr						4158	5072

T23 : 4158 tonnes pa @ £200 = £ 831600 pa = £5544 per day;
S97 : 5072 tonnes pa @ £200 = £1014400 pa = £6763 per day;
Diff: 914 tonnes pa @ £200 = £ 182800 pa = £1219 per day.

These detailed figures show that the S97 short, fat frigate, at the same displacement and operational speed profile as the T23, uses **22%** more fuel per year, not **100%** more, as Bath have suggested. The total daily running cost of a frigate is about £125,000 per day, to which the £1,219 daily extra fuel-burn of the S97 would add just under **1%**, or about **£3.66m** though the ship's life. And, incidentally, it appears that the fuel cost of a frigate is about **4.4%** of daily running costs, not the 10% suggested by Bath.

Against the extra fuel cost, which is less than one-fifth of the figure suggested by Bath, the S97 would show substantial savings on the cost of building, outfitting and maintenance - perhaps as much as **£10m-£30m** per ship.

This saving could either be used to reduce the defence budget or to install extra powering in the S97, allowing speeds high enough to match and catch enemy vessels.

Seakeeping and damaged stability

Seakeeping and ability to survive damage are a vital part of ship design. If a ship is unable to survive damage, or if it handles poorly in heavy seas, the crew will be put at risk or made so uncomfortable that they cannot perform effectively.

Roll period: Bath said that, although wetness and slamming in the S90 were good, the roll period was very short - 7 seconds against 10-12 seconds for the Leander - and would make the men uncomfortable. In fact, the theoretical roll periods of the S90 and Leander are 8.04 and 9.3 seconds respectively, and the measured roll periods are 8.04 seconds and 9.5-10 seconds respectively.

Roll accelerations: Bath said that roll accelerations on the bridge would be unacceptable. But the roll angles of the S90 in most seas are 4 degrees, or about 20%, less than those of the Leander, reducing roll acceleration considerably.

Helicopter: Bath said that the helicopter platform on the S90 would roll unacceptably. But BHC (ie Westlands) say that the roll characteristics of the S90 are perfectly acceptable for helicopter operation.

Gravitational metacentre: Bath said that the quick roll of the S90 was caused by the greater gravitational metacentre, which is at 5m above the centre of gravity rather than the 1.5-2m which is ideal. But the metacentric height of the S90 as submitted in her final form to MoD was 3.5 metres, not 5 metres.

Stabilising fins: Bath said that the apparently better roll period measured in the 1/10-scale model tests of the S90 against the Leander had been achieved by the fitting of unusually large stabilising fins. But the stabilising fins fitted to the S90 model were only 20% geater in area than those fitted to the Leander model, which also had a considerable area of bilge-keel, so that the stabilising surfaces on the Leander were actually more than 5 times greater than those on the S90.

Ballasting: Bath said that heavy ballasting of the S90 model was also partly responsible for its good handling in the sea-trials. But the amount of ballast in the model was normal, and was set by BHC, who conducted the tests.

Survivability: Bath said that the S90 would be les able to withstand being holed below the waterline than a long, thin ship because she would ship more water in each compartment, since the compartments were wider. But the reserve stability of a broad-beamed boat is considerably greater than that of a long, thin hull. The S90 as submitted to MoD comfortably met the damaged stability standards which MoD had specified.

A naval architect commented: "Some of these long, thin naval ships have the most horrific motions in large seas which must be extremely debilitating to the crew." There is good reason to suppose that the seakeeping of the S90 would be as good as, and in many respects better than, that of a conventional frigate.

Displacement

The Sirius S90 as submitted to MoD was designed at 2800 tonnes, but the T23 is 3850 tonnes. Bath said that the S90 as designed might not be able to accommodate all the crew and equipment needed to run a warship with all the capabilities of the T23. TGA had designed a ship for 100 men, when the NSR had specified 165. The T23 displacement of 3,700 tonnes was the minimum necessary to take the full complement and a full engine, equipment and weapons fit.

The Type 23 started out at 2,700 tonnes, as the original Naval Staff Requirement shows. Accordingly, TGA were asked to design a ship to this specification and were not informed when the displacement of the T23 was increased to accommodate extra weapons, engines and helicopter hangar space. It seems unreasonable, therefore, that TGA should be criticised for having designed a ship of greater displacement and with a smaller crew. The final, full-load displacement of the T23 is not, as Bath said, 3,700 tonnes, but 3,850 tonnes.

Design and performance of the Hong Kong Patrol Craft (HKPC)

TGA claim that the Hong Kong Patrol Craft incorporates certain features of their designs which were tested at the Vickers tank at St. Albans by British Shipbuilders. Hence, among other factors, the HKPC is able to go faster than tank-tests predicted. If the HKPC had not incorporated the TGA designs, its speed would have been closer to that of the T10 (i.e. 21 knots rather than 28, against a specification of 25-26 knots).

Bath said that they were unaware of any special features in the S90 design which marked it out from other short/fat ships; and that the top speed of the HKPC on trials was 25 knots.

In fact, the special features, which the designers think cause hydrodynamic lift and hence better speed in relation to powering, have been included in the HKPC. These features are present in no other craft of the displacement of the HKPC, with the exception of the Osprey and other TGA hulls. Furthermore, the top speed of the HKPC on trials was not 25 knots but more than 28 knots, according to the Naval Architect of February 1984. Like the Osprey from which TGA claim it is derived, the HKPC performed spectacularly better in full-scale trials than the tank-tests had shown.

Conclusions

There are several significant divergences between MoD's assessment of the TGA designs and this assessment, These divergences give grounds for suggesting that the design deserves to be looked at again, perhaps by an independent team of experts.

Among the questions for defence policy raised by this issue, the following are important:

Cost of the Type 23: It appears from the figures that the T23 is a very expensive ship indeed and it seems unlikely either that the British Government will be able to afford more than a very small number or that, at the price, there will be many export orders.

Cost of the S90/S97: It appears that the cheaper hull-form of the S97 might produce savings on build-and-refit costs greater than the "single-figure millions" of which Bath have spoken, and that the extra fuel cost of the short/fat design might be small in comparison, particularly since oil prices are falling.

Performance of the Type 23: In relation to the speed of Soviet warships and submarines, the Type 23 is very slow. Since it is so slow, it has to rely on its helicopter to deliver the punch, in the shape of a Stingray torpedo. But that torpedo has to be lightweight or the helicopter cannot lift it as well as the sonobuoys it needs to pinpoint the target vessel. And the Stingray itself is both slower than the submarines it is designed to attack and incapable of operating with full effectiveness at great depth. The Type 23, therefore, may be unable to fulfil its primary role.

Performance of the S90/S97: MoD's stated objections to the TGA designs is that they are far from proven. The latest tank-tests at BHC, coupled with details in the validation report for the original S90 project, overcome many of the objections in the report of the DSAC hull committee. However, the case in favour of the S90/S97 is not proven either, because no prototype of a frigate-scale vessel has been built with the TGA hull-form.

Hydrodynamic lift, resistance and powering: It is certain, from the elementary physics of fluid mechanics, that Mr. Rawson was wrong to suggest that lift as measured in tank models would not be present in full-scale geosims because of the "square-cube" law. It is likely, from our examination of the resistance and powering measurements, that the **significance** of lift, rather than its mere **presence**, gives an advantage to the TGA hull-form at speeds well below the 40 knots mentioned in the DSAC report and echoed by Bath. The S90's advantage seems to come in exactly at the top of the present operational range - i.e. 29-30 knots.

In a letter to the Policy Unit, Bath say that "the RN has no requirement for ships capable of 40 knots" - which, because of the punishing power-penalty imposed by long-thin hull-forms at these speeds, is not surprising. For example, the Russian Kashin Class destroyers require 150,000 BHP to achieve 45 knots, and their fuel endurance is absurdly low.

We asked Bath to calculate the minimum displacement and powering requirement of a warship carrying a normal payload and travelling 3,000 nm at an average speed of 40 knots without refuelling. Bath did not answer this precise question, but they did write that the full-load displacement of an S90 capable of such speed and endurance would be 6,000 tonnes at the very minimum.

At present a £10m consortium is designing a TGA hull to break the Blue Riband record across the Atlantic, which happens to demand an endurance of 3,000 miles at an average 40 knots. Based on tank-tests, the full-load displacement of that ship will be below 1,000 tonnes and its final speed will approach 50 knots. This is a good illustration both of the discrepancy between Bath's methodology and that BHC, and of the astonishing potential of the TGA design - if it works.

Fuel cost: The detailed figures prepared by TGA at our request indicate that, because the powering requirement is not as great as that estimated on the basis of Mr. Rawson's statement, the cost of the extra fuel used by the S90/S97 would very much less than MoD's estimates.

Seakeeping of long/thin ships: In many respects, the inherent stability of the short/fat design give it better handling than the notoriously uncomfortable long/thin frigates of conventional, long/thin design, which has by no means had uniform success. For instance, the original Leanders (on which Admiral Bryson's puzzling Fig. 16 Leander resistance curve may be based) were narrow, 2,200-tonne vessels. They had to be widened to make them stable. Type 22s, too, are notoriously short of stability. And the longitudinal stresses imposed by the long/thin design not only make for an uncomfortable ride but also cause expensive structural problems. For instance, the stretched T42s are prone to breaking-up; and some T21s have had to be "belted" with steel to hold them together.

Seakeeping of the S90/S97: Many sources have confirmed to us that there is no reason to suppose that the TGA hull-form would handle less well or survive damage less capably than a conventional hull. It is significant that the grandfather of Peter Thornycroft of TGA was the first to design long/thin ships, speed being the chief reason. Yet, in the later part of his life, as he saw the power-to-weight ratios of marine engines falling, he devoted himself to the work on fast short/fat warships of which the current TGA design is the culmination.

Export potential: The Navies of New Zealand, India, Pakistan and Burma are among those, according to TGA, who have expressed interest in the TGA designs. In all these cases, attempts were made by MoD officials to discourage the Navies concerned from placing orders, on the grounds that the designs were unworkable. The Burmese Navy, undeterred, ordered a fleet of patrol-vessels incorporating the TGA hull-form and are said to be pleased with them. It is, we are told, the normal practice of MoD not to spoil the chances of commercial operators in this way. If the normal practice is not being followed in this case, it should be.

Should the case for the S90/S97 be reopened? On the evidence available, there appears to be room for reasonable doubt whether the MoD has fully and fairly evaluated the S90 design. It is disturbing that during the MoD's assessment of the design the then Chief Naval Architect appeared to be under a misapprehension that hydrodynamic lift in the S90 design would not transfer from the test-tank to the full-scale ship. That misapprehension was subsequently replaced by a correct statement of the position, but the Navy's rejection of the design appears still to be based, at least in part, on the original misstatement. This, in itself, is a reason for reopening the case.

CHRISTOPHER MONCKTON

30 January 1986

POINTS OF DIFFERENCE : SUMMARY

This list sets out the chief points of difference between MoD's position (column A) and what we think may be nearer the true position (column B).

	A	B
Cost of Type 23 frigate	£150m	£179-193m
of which, helicopter	£11m	£24m
Hydrodynamic lift in S90?	No	Yes (BHC)
Lift/displacement, full scale	1/25	1 (Dr Garwin)
S90/Leander resistance advan.	Over 40 knots	Over 33/34 knots
S90/Perry resistance advantage	Over 32 knots	Over 29/30 knots
Propulsive coeff. of Leander	0.467 or 0.6	0.55 (BHC est.)
of S90	(now) 0.6	0.6 to 0.7 (BHC)
Correlation factor of S90	0.9 to 1.04	0.86 to 0.96
Installed power of S90	c. 45MW	35MW (NMI)
Min. Displ. for 3000nm @ 40kt	6000+ tonnes	1000- t (BHC)
S97 throughlife extra fuel cost	£10-20m	£3.6-6m (TGA/RR)
S97 annual extra fuel cost	£1m	£183,000 (")
Roll period of S90	7 seconds	8-8.5 seconds
of Leander	10-12 seconds	9.3-10 seconds
Acceptable bridge roll accel.?	No	Yes
Gravitational metacentre of S90	5 metres	3.5 metres
1/10 model ballasted properly?	No	Yes (by BHC)
Size of S90 stabilising fins	(S90 model	144 sq. in.
of Leander stabilising fins	much bigger	120 sq. in.
of Leander stabilising surfaces	than Leander)	760 sq. in.
Reason for long/thin warships	Many reasons	Speed/power
Is speed important to the Navy?	No	Yes (S Shapcott)
Does the Navy need a 40kt ship?	No	Yes (")
Top speed of Soviet destroyers	33 knots	38 kt (Jane's)
of HKPC	25 knots	28+ kt (NavArch)
of Leander frigate	30 knots	28 knots (Capt)
S90: Acceptable arcs of fire?	No	Yes
Good radar coverage?	No	Yes (Y-ARD)
Electronic interference?	Yes	No (Capt Prince)
Good helicopter platform?	No	Yes (BHC)

THE COST OF NAVAL FRIGATES : WHERE LIES THE TRUTH?

Leander Class : mid-life refit only

Date	Cash	'86-price	Source
1980	£ 30m	£ 43m	Times, 1983 December 8
1983	£ 80m	£ 93m	Times, 1983 December 8

Type 22

Date	Cash	'86-price	Source
1983 August 1	£132m	£153m	Daily Telegraph
October 19	£130m+	£151m+	Times
October 19	£150m	£174m	Ian Stewart MP, Telegraph
1984 May 15	*£125m	*£137m	Lloyds List *upgraded T22
December 27	£135m	£148m	Times
December 27	*£170m-	*£187m-	Times *inc. stores, fuel
1985 January 29	£140m	£147m	M Heseltine MP, Times
1986 April 9	£100m	£100m	Times
April 23	£170m	£170m	BBC2 "MoD" programme

Type 23

Date	Cash	'86-price	Source
1980	£ 62m	£ 90m	Sunday Times, 1983 Sep 11
1981	£ 70m	£ 91m	J Nott MP Tel, 1983 Aug 1
1983 August 1	£110m	£128m	Daily Telegraph
September 11	£120m	£139m	Sunday Times
October 19	£100m	£116m	Times
1984 October 29	£110m+	£121m+	Financial Times
December 27	*£110m	*£121m	Times *exc. stores, fuel
1985 January 29	£110m	£115m	M Heseltine MP, Times
May 2	£110m	£115m	Daily Telegraph
May 6	£120m	£126m	Sunday Times
November 2	£125m	£131m	Daily Telegraph
	£200m?	£210m?	Jane's "Fighting Ships"
1986 January 27	£120m	£120m	Daily Telegraph

EH101 Westland helicopter for Type 23 frigate

1981	£ 19m	£ 24m	Official estimate
1986 April 17	*£ 13m	*£ 13m	N Lamont MP, Times
			* development cost only

The Type 23 was originally intended to be cheaper than the Type 22: if Jane's estimate is right, it will be considerably more expensive. Are the costs of this programme being deliberately understated to cast it in a more favourable light against the competition? How many frigates can be afforded at the true price?

ANNUAL FUEL CONSUMPTION OF S97 @ 3600 TONNES V. T23 @ 3600 TONNES BASED ON ROLLS ROYCE ESTIMATES OF TIME SPENT AT SPEED

SPEED (kt)	HOURS (pa)	TOTAL POWER (kW)		FUEL CONSUMPTION (kg/kWh)		(tonnes/hr)		(tonnes/yr)	
		T23	S97	T23	S97	T23	S97	T23	S97
28.0	90.0	28000	36000	0.236	0.225	6.610	8.810	595	729
26.0	201.6	21112	26185	0.247	0.237	5.215	6.206	1051	1251
22.5	342.0	10663	14696	0.285	0.285	3.040	4.115	1040	1407
19.5	583.0	5073	6637	0.285	0.280	1.446	1.859	843	1084
16.5	745.0	1865	1865	0.250	0.250	0.466	0.466	347	347
13.5	756.0	821	746	0.250	0.250	0.205	0.186	155	141
10.5	576.0	671	597	0.250	0.250	0.168	0.149	97	86
4.5	306.0	373	336	0.260	0.260	0.097	0.087	30	27
	3599.6 = 150 ship-days/yr							4158	5072

NB: SM1A (T23) and SM1C (S97) Spey gas turbines above 17 knots: Paxman Valenta Diesel-Electric Engines below 17 knots.

T23: 4158 tonnes pa @ £200 = £ 831600 pa = £5544 per day;

S97: 5072 tonnes pa @ £200 = £1014400 pa = £6763 per day;

Diff: 914 tonnes pa @ £200 = £ 182800 pa = £1219 per day.

Conclusion

The S97 short, fat frigate, at the same displacement and operational speeds as the T23, uses 22% more fuel per year. The total daily running cost of a frigate is £105,000: hence the £1219 daily extra cost of fuel for the S97 increases daily and thus through-life running costs by only 1.16%. Assuming a 20-year ship-life at 150 days per year, the extra fuel used by the S97 would cost £3.66m.

Against this, the S90 would show savings on the cost of building, outfitting, maintenance and refits which, even allowing for the extra cost of using uprated rather than standard Speys for the extra horsepower, might be as much as £15m-£25m.

Thus the overall saving on each S97 could be around £11m-£21m, or, on 50 frigates, £500m-£1000m. Furthermore, the S97 has the potential, if more power is installed, to achieve substantially higher maximum speeds than the T23, if required, without the powering penalty which the traditional hull-form imposes.

RESISTANCE AND PROPULSION

(1+x) = Model/full-scale correlation factor
(usually 1.04 to 1.16, but 0.86 to 0.96 for S90).
BHP = Installed brake horsepower of vessel = SHPx1.03
D = Displacement in tons.
DHP = Delivered horsepower = (EHPx(1+x))/QPC
D/L = Displacement ratio = D/(L/100)/(L/100)/(L/100)
EHP = Effective horsepower of the bare hull = (DxVxR)/325.5
(v. Prof. Kenneth Davidson, Princ. of Nav. Arch., 1932).
Eta h = Hull efficiency.
Eta o = Open-water efficiency of the propeller.
Eta r = Relative rotative efficiency.
g = Gravitational constant (usually cancelled out).
L = Length of vessel at the waterline in feet.
PC = Propulsive coefficient
= EHP/BHP = QPC/((1+x)x(dhp factor)x(shp factor))
QPC = Quasi-propulsive coefficient = Eta h x Eta o x Eta r.
R = Resistance in lb per ton.
SHP = Shaft horsepower = DHPx1.03
V = Velocity of the vessel in knots.
$V/\sqrt{L}$ = Quasi-Froude number, to measure wave-making resistance.
$V/\sqrt{gL}$ = Froude number (the quasi-Froude no. is generally used).

The 1/x-scale model: Testing of hull-forms is done in tanks using scale models - typically 1/10, 1/25 and 1/43. To allow for the correct effect of gravity and hence wave-making resistance, a 1/x-scale model is run at full-scale speed divided by the square root of X, thus making the Froude number (or the quasi-Froude number $V/\sqrt{L}$) the same for the model as for the full-scale vessel.

Resistance: Resistance of the model is measured and a curve plotted showing resistance against speed. At the maximum required speed, the resistance is read off and the effective horsepower (EHP) is calculated. The EHP is the power required to move the bare hull through the water.

The (1+x) correlation factor: Tank-tests do not always give an exact prediction of how a full-scale model will perform. Hence a correlation factor, known as (1+x) and usually in the range 1.04 to 1.16, is used as part of the formula for converting the effective horse-power as measured on the basis of the resistance curve into the installed horse-power that will actually be needed in the full-scale vessel.

The quasi-propulsive coefficient: The QPC is the product of the hull efficiency, the propeller open-water efficiency and the relative rotative efficiency, typically ?0.8-0.95 each.

The propulsive coefficient: The PC is the effective horse-power divided by the installed horse-power at a given speed. The figure usually quoted is for the maximum speed. The usual range is 0.52 to 0.58. A high propulsive coefficient means less power will be needed to drive the full-scale ship.