ENGINEERING IN THE ROYAL NAVY— TOWARDS THE AUTOMATIC WARSHIP

BY

VICE-ADMIRAL SIR HUGH THOMPSON, K.B.E., F.ENG., F.I.MECH.E.
(*Chief Naval Engineer Officer*)

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ABSTRACT

The problem of maintaining effective naval forces is complex; on a changing international and national view of the need for armed forces is superimposed a likely severe shortage of manpower and increasing cost of manpower per capita. Against this background, developments in the design of escort ships over the period 1960 to 2010 are examined, together with the major contribution that increasing automation can make to solving the problem.

Introduction

A centenary conference is an appropriate time to review progress, but 'Engineering in the Royal Navy' is too wide a field for a single paper. It is intended therefore to narrow the task to a look at surface escorts and some of their equipment over the fifty years from 1960 to 2010, providing some historical basis for a glance to the future, 'Towards the Automatic Warship'. But naval engineering, indeed the Royal Navy itself does not exist in a vacuum. The North Atlantic Treaty Organization is the foundation of the United Kingdom's defence and security policy. Despite significant recent initiatives towards arms control and reduction there still remains a major Soviet and Warsaw Pact threat to this Alliance. In particular the unique problems associated with maritime arms control present a major obstacle to any agreement in the near future. Thus the Royal Navy's role in providing the vast majority of in-place maritime forces in the Eastern Atlantic and Channel areas, and a major contribution to forward defence in the Norwegian Sea, is likely to remain a requirement for many years to come. Finally there continue to be significant threats to Western interests outside the NATO area, recent examples having necessitated the Armilla patrol and mine clearance activities in the Gulf. The ability to deploy forces Out of Area on a worldwide basis remains an essential component of U.K. Defence Strategy.

The other great and related factor which bears upon the Navy is the level of support which the Government is prepared to devote to defence. In any democracy this level is likely to be less than that desired by the Armed Forces, and lack of money is a recurring theme, or rather problem, throughout the Services. This lack of money means that an optimum balance of the available resources has to be achieved to ensure there is adequate for all activities such as the provision of new equipment, the maintenance of ammunition stocks and keeping sufficient fuel for a satisfactory level of operational readiness; at the same time there has to be provision to ensure the supply of that extremely expensive and valuable commodity—manpower—which is the central theme of this paper. A look at this topic is necessary before moving on to engineering matters.

Manpower

To recruit and retain volunteer forces, they need to be appropriately paid. Despite the numerical strength dropping by 19% since 1960, total expenditure on armed forces pay has risen steadily, and remains at about 20% of the defence budget. This budget is barely increasing in real terms, and yet the proportion of it devoted to naval equipment—whose costs rise at a rate above that of inflation—has also risen steadily, and continues to grow. This puts increasing pressure on the minimization of manpower, particularly as the directly associated costs are so high; for instance, it is estimated that today's cost of adding one more man to the crew of an escort is £30K, and the through-life costs for that escort of the additional man should be counted in millions of pounds. It is also frequently forgotten that the man's pension has still to be paid after he has ceased to be a member of the Royal Navy. Designers are therefore looking to achieve the same capability with fewer men, perhaps by automation, so that force levels remain constant while naval manpower reduces.

Secondly, however successful recruiting is, there will be fewer people to choose from in the future, when many employers and professions are seeking an upgrade in skills. The demand for graduates is predicted to rise in the next decade, although the number of students is forecast to decline from a peak of 124,000 in 1992 to a low of 113,000 in 1998. To compound the Navy's problem, there is a swing away from science subjects; between 1985 and 1987, a drop of 10% in applications for university science and engineering courses contrasted with 14% increases in applications for business studies. Thus a rise in the demand for skilled people coincides with a demographic trough reducing the number available.

In general cases the recommendation of the Department of Employment is to widen recruitment policy to include more of the qualified but disadvantaged sectors, such as women, the middle-aged, and the disabled. All these recommendations have been examined by the Navy, but only an increase in the recruitment of women offers any redress.

Women have, of course, been recruited into the WRNS since World War I, but government policy is that they should not be employed in combat zones. However, such is the lack of qualified people, that the range of jobs that women do in the Navy is ever widening, and now includes shore-based engineer officer posts where their performance has been found to be very satisfactory. This trend needs careful monitoring or there will not be enough shore jobs for the men and consequently insuffìcent dissemination of sea experience ashore. There is now some discussion of altering the role of women in the services which could give them further opportunities, but the implications of their employment at sea in warships do need careful examination.

The shortage of qualified people, affected as much by the improved social and economic conditions in the country as by demography, is inevitably increasing the competition for their services; so, do people the Navy needs still want to join? Research shows that although the student pacifism of a few years ago has largely gone and the requirement for the armed forces is accepted, recruitment has to be viewed within the present atmosphere of arms control. Many prefer to join an expanding company. The Service's graduate starting salary is presently below the national average; and service conditions, especially separation from the family, are no longer so readily borne. The Navy will thus need to fight hard to attract and retain the people it needs, and ensure that all those who have the potential have the opportunity to rise to the top. At the same time the requirement to employ so many people must be reduced.

TABLE I—*Reductions in ships' complements*

Type	*Name*	*Introduced into Service*	*Total Complement*	*Reduction*
Aircraft Carrier	*Hermes* *Invincible*	1959 1980	1071 674	47%
Destroyer	COUNTY Class Type 42	1961 1976	452 258	43%
Frigate	LEANDER Class Type 23	1964 1989	231 169	27%
Nuclear Submarine	*Valiant* *Trafalgar*	1966 1983	137 128	7%
Ballistic Missile Submarine	*Resolution* *Vanguard*	1967 1992	148 130	12%
Diesel Submarine	*Oberon* *Upholder*	1961 1988	66 46	30%
Mine Counter Measure Vessel	TON Class *Sandown*	1951 1989	38 34	11%

Trends in design and technology have all been towards a significant reduction in the number of operators and maintainers needed for a given item of equipment, and for the reason noted above this trend must continue. The Navy's good record for reducing manpower in successive classes of warship over the years (TABLE I) allows the future to be faced with confidence.

To provide a yardstick to measure progress over the chosen fifty year study period, the following paragraphs examine the evolution of the surface escort using three ship classes as examples of their design eras.

The Surface Escort

H.M.S. *Devonshire*, (FIG. 1) the first of the County Class destroyers, was launched in 1960. She was much larger than any previous destroyer—more the size of a light cruiser—but her role was as an escort. *Devonshire* carried many new weapons and embodied advances in her design, and had a ship's company of 450. She had several firsts which make her worthy of examination and comparison with today's and tomorrow's designs: Combined Steam and Gas propulsion (COSAG), guided weapons, the Comprehensive Display System (CDS), and a helicopter.

FIG. 1—H.M.S. 'DEVONSHIRE' AT SEA IN THE EARLY 1960s

FIG. 2—H.M.S. 'NORFOLK', THE FIRST TYPE 23 FRIGATE, ON SEA TRIALS

HMS *Norfolk* (FIG. 2) is the first of the Type 23 frigates and is now on sea trials. Intended initially as a specialist ship for towed sonar array operations, the design has developed within severe cost constraints into a general purpose escort. Again, there are firsts in this design, such as Combined Diesel-Electrical and Gas propulsion (CODLAG), vertically launched missiles, and reduced radar, noise, and infra-red signatures. She also has a much smaller crew (145) than previous escorts of comparable size and capability.

What will be the characteristics of the escort entering service in 2010? A clear pointer is the NATO Frigate Replacement (NFR 90) at the present in the Project Definition stage (FIG. 3). In general the trend is likely to be 'more of the same': more attention to reducing signatures, greater ecomony, lower costs, greater ability to attack appropriate targets, a greater ability to defend herself, a greater ability to continue to fight after suffering damage, and to operate with fewer men.

Hull

The *raison d'être* of the COUNTY Class was the deployment of the first naval guided weapon, the Area Air Defence System, Seaslug. There was considerable pressure for early deployment of this major system, but the resulting ship design was dominated by it in a way that today appears unreasonable.

After the COUNTY Class, escort development has progressed through five more achieved designs before reaching today, and they featured: increasingly efficient seagoing hull forms, the completion of the change to gas turbine propulsion, the need to accommodate ever larger or more numerous helicopters, moves towards modularity of weapon systems and much improved equipment removal routes. On the way, a detour into aluminium superstructures was made, which is not likely to be repeated. However, one aspect

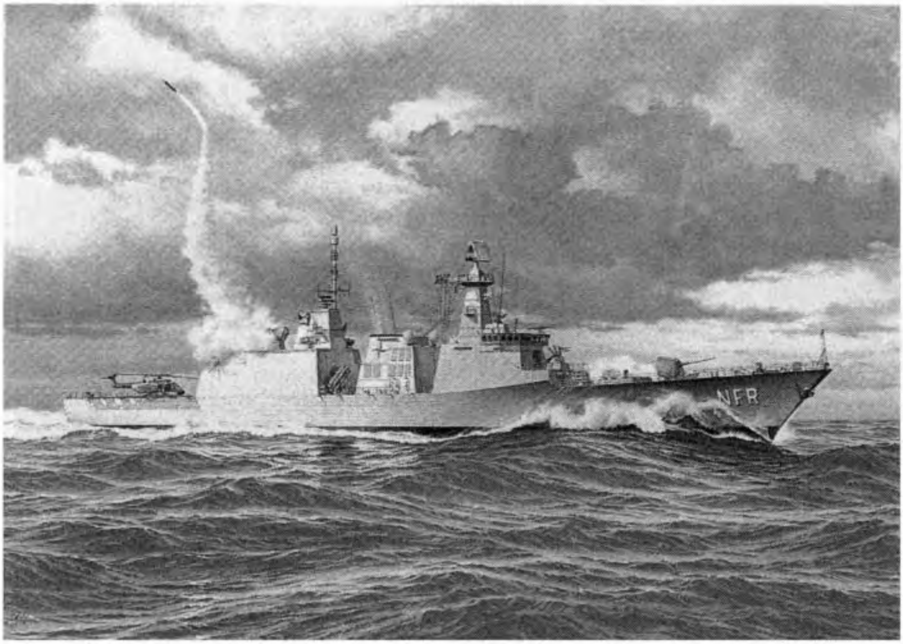

FIG. 3—AN ARTIST'S IMPRESSION OF THE NATO FRIGATE REPLACEMENT (NFR 90)

which is less well advertised is the reduction of signature, and this has been a 'quiet' trend throughout the period. It started with acoustic noise, to make the escorts' sonar more receptive and attract less attention from submarines. Heat signature was next addressed, in view of the greater output from gas turbines and the development of infra-red missile homing heads; and then, more recently, radar echoing area (REA) has been tackled.

The essential features of the Type 23, when first contemplated in the late seventies, were to be: a quiet platform to maximize the effectiveness of the towed sonar array, high endurance at moderate towing speeds, a flight deck for a medium helicopter with the ability to refuel and rearm it, and hull and superstructure configured to minimize REA, all within a maximum stated price. Size and cost were to be kept down by limiting the size of the crew. The result was a sketch design of about 2500 tonnes. Quietness was to be achieved largely through the new propulsion plant machinery on sound-absorbing rafts, and REA reduction depended principally on minimizing large perpendicular reflecting areas and corners by detailed design, and by the use of radar-absorbent material.

Reduction in ship motion is a major consideration for improved ASW capability, giving increased operational availability of helicopters and sonars. The Small Waterplane Area Twin Hull (SWATH) (FIG. 4) form offers large reductions in motion, particularly for vessels under 4,000 tonnes displacement. It would also provide improvements in the environment for bow sonars, handling arrangements for towed arrays, and more deck space for helicoptors.

At first sight SWATH looks an attractive option for the ASW escort of 2010, but nothing comes free. The main disadvantage of the inverted U-form is inefficency in enclosing usable space compared to the box-like cross section of a conventional hull. This results in high structural weight in relation to the payload volume, with consequential effects on power and fuel requirements. Although SWATH is attractive for specific tasks, such as sonar surveillance and oceanographic survey, its development has not yet reached the stage

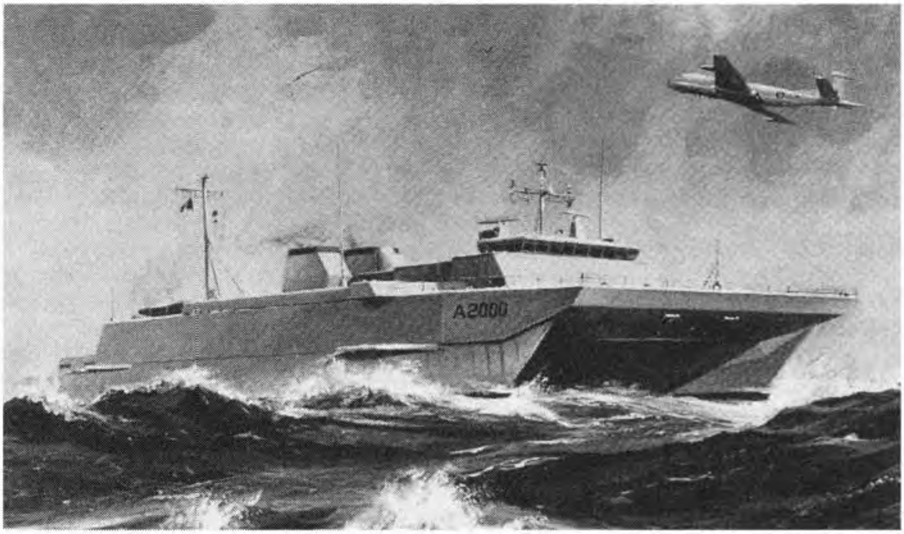

FIG. 4—SMALL WATERPLANE AREA TWIN HULL (SWATH)

where it can show an overall advantage for the general escort role. However, the push towards smaller complements, and the developments in all electric machinery and lighter composite structures could tip the balance in its favour.

Provision of helicopter operating and maintenance facilities was little more than an afterthought in H.M.S. *Devonshire* (FIG. 5). In the Type 23, their

FIG. 5—H.M.S. DEVONSHIRE'S AVIATION ARRANGEMENTS SANDWICHED BETWEEN THE SEASLUG DIRECTOR AND LAUNCHER; THE PARTLY OPEN HANGAR DOOR CAN BE SEEN ON THE LEFT

provision is the dominant feature in determining upper deck layout. In the distant future it may be that highly capable, smaller pilotless vehicles will allow a reversal of this trend.

What else can be expected in the hull field in 2010? A steel stiffened GRP plate composite is a good prospect for superstructures, as it is lighter than steel and has both lower reflectivity and fewer maintenance requirements. The use of steel or nylon laminates for the armour protection of important equipment and services is also probable.

Propulsion

By the time design work started on a boost gas turbine for the County Class, the Navy had had 10 years' operating experience of a wide variety of gas turbine types. The conclusions at the time were that complex cycles led to bulky and expensive engines and, despite their better and flatter fuel consumption curve, a simple cycle type was preferred. Secondly, something more robust and of longer life than the aero engine was required, and finally it was concluded that ball and roller bearings could not give the life and reliability required for naval use. These conclusions resulted in the G6 gas turbine, a 5·6 MW engine with a specific weight at maximum power of 2·9 kg/kW. Compared to the first Gatric simple cycle gas turbine fitted in a motor gun boat in 1946 with its 1·7 kg/kW, the G6 can best be described as being designed along conservative lines.

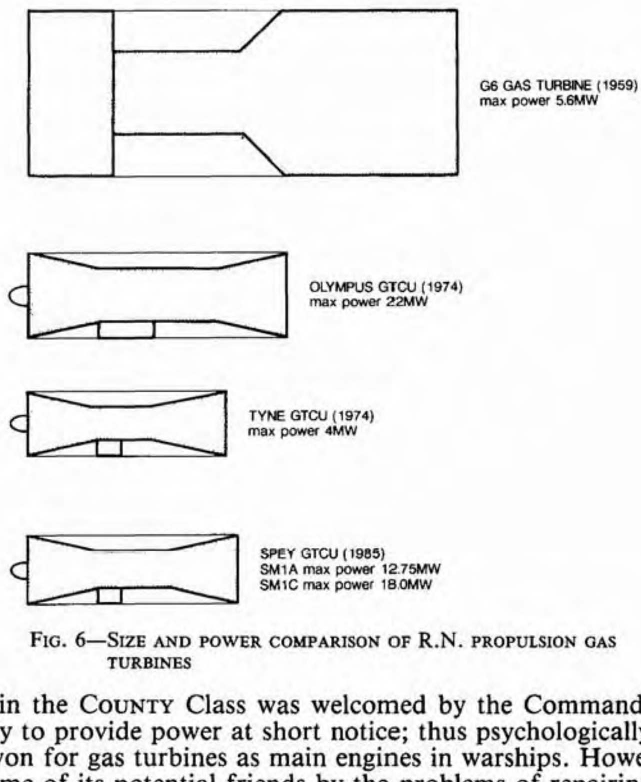

FIG. 6—SIZE AND POWER COMPARISON OF R.N. PROPULSION GAS TURBINES

The G6 in the COUNTY Class was welcomed by the Command by reason of its ability to provide power at short notice; thus psychologically the battle had been won for gas turbines as main engines in warships. However the G6 had lost some of its potential friends by the problems of repairing it *in situ*, and the exciting prospect of a substantial reduction in through-life costs—a topic then being taken more seriously than hitherto—was dimmed. Also, experience with Proteus in the BRAVE Class had shown that aero-derived engines were rugged enough to survive at sea and could offer life measured in thousands rather than hundreds of hours. Thus when the decision to go to all gas turbine propulsion was taken in 1967, the lightweight compact aero-derived gas turbine won the day by reason of its combination of high power with low weight and small space requirements. FIG. 6 shows the approximate relative sizes of the various engines. Very substantial manpower savings in marine engineering complement followed directly from the implementation of this policy (typically 30%) which, when coupled with reduced repair costs, has produced much lower through-life costs.

As for the future of gas turbines, they must clearly fit in with the concept already outlined for the future escort. For that ship, it is expected that signature, principally noise, will dominate the debate concerning the direction that future main propulsion and power generation systems should take. The key issues can be identified as the highest speed at which the ship is required to remain quiet, the percentage of operating time spent at or below this speed, and endurance. There is every indication that quiet speeds will rise and that the future escort will spend a greater proportion of her time at or near this speed. The past reasons for rejecting complex cycle gas turbines are becoming largely irrelevant with the possibility of using the combination of an aero-derived gas turbine core engine with an advanced design of heat exchanger, using new materials. Thus the demand for low manpower requirements and high efficiency for cruise power will favour a modern technology gas turbine, employing a combination of variable geometry, regeneration and intercooling.

Moving on to transmission systems, the Royal Navy has relied primarily upon mechanical systems; the use of electrical drive has been restricted to submarines. The only exception came in 1962 when the HECLA Class of survey ships required a simple but reliable propulsion and generation system capable of supplying a high auxiliary load, with the capability of fine control at low speed. A diesel-electric system of 1·83 MW was chosen with a constant current d.c. loop and the armatures of the three generators connected in series.

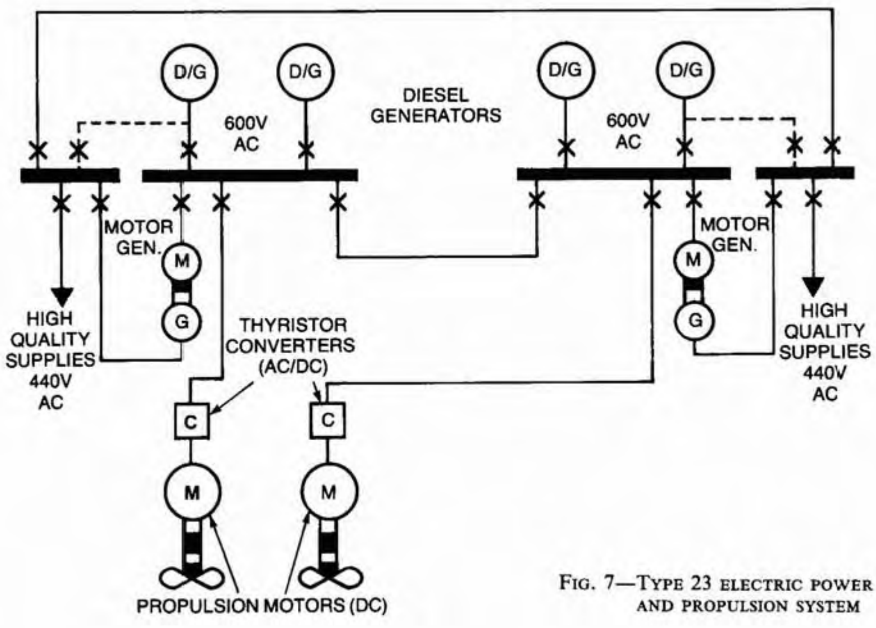

FIG. 7—TYPE 23 ELECTRIC POWER AND PROPULSION SYSTEM

The Type 23 has now returned to electrical propulsion, but for a quite different reason—low noise. Only by using a diesel-electric propulsion system for low powers, could the acoustic requirements be met, while obtaining the fuel economy of diesel engines. There was the additional advantage of avoiding the need for a reversing gearbox, and a fixed pitch propeller could be used, leading to an even simpler propulsion package.

The electrical system in the Type 23 (FIG. 7) is based on the experience of the HECLA Class, and using lessons learned from diesel-electric propulsion in submarines. An integrated arrangement is used, with the four diesel generator sets providing a central power supply of 600V, 60Hz, 3 phase. Thyristor converters rectify this supply for the propulsion motors, and motor-generator sets provide 440 V 60 Hz for ship's services. D.C. motors were chosen because they offer lower noise and better operating characteristics, and because a.c. motors of that power would have necessitated considerable development work. These advantages far outweighed the additional commutator and brushgear maintenance required.

It seems inevitable that low acoustic signature will still be a necessity in 2010, and an electric propulsion system seems appropriate. The inherent flexibility such propulsion systems offer allows a wide range of prime movers to be considered; the most likely contenders are diesel engines in the 1200 to 1500 rev/min range and gas turbines in the 2 to 25 MW power range. Electric propulsion also permits arrangement flexibility (such as is required in SWATH), and redundancy to remain operational in face of defects. The ability of those parts of the plant such as shafts and main bearings, necessarily sited low in the ship, to resist shock damage will continue to require subtlety of design. Finally, an integrated electrical system could also provide the pulsed power for directed energy weapons or rail guns which could then be in an advanced state of development.

Guided Weapons

Seaslug started its development after World War II, as an area anti-aircraft weapon capable of engaging the high-flying bomber at ranges of twenty-five miles. An optional nuclear warhead was envisaged and a large missile was therefore needed to carry it. The alternative conventional blast warhead had also to be large because of the relatively inaccurate beam-riding guidance method used. Two-component liquid fuel (kerosene and nitric acid) was chosen for the sustainer motor because solid rockets of that size could not be reliably manufactured, and this resulted in a missile design with two fuel chambers, divided by the wing roots. Concern over the safety of liquid fuel in ships, and the sheer bulk of the missile once the wrap-round boosts were added, dictated horizontal stowage and subdivision of the magazine by power-operated blast doors. The result was a vast, mechanically handled magazine which stretched from the trainable framework launcher at the stern, to the area of the bridge; although solid fuel was ultimately substituted, it was too late to change the magazine arrangement. The system's dependence on services was widespread, though most of these were derived centrally from 440 V power; they included converted supplies, hydraulics, high pressure air, cooling and stabilization, with very little redundancy. Its ability to remain operational after the ship had sustained damage was very limited, particularly as the system physically stretched over much of the ship's length.

In time, and especially as the threat became more menacing, it was recognized that Seaslug was only of very limited use against fast small low targets, and was easily overwhelmed by multiple attack.

Seaslug and the smaller close-range Seacat led on to their successors, Seadart and Seawolf; the latter is a world-leading anti-missile system and is deployed in the Type 23. Seawolf itself has not stood still since first deployment in H.M.S. *Broadsword* ten years ago. Although it is a point defence missile with only a limited area capability, it has been progressively developed to keep pace with the advancing threat.

From the outset, the Seawolf system was designed to be modular, thus minimizing shipfitting difficulties, and to engage missiles aimed at the ship, as well as any launching aircraft. This requirement demanded exceptional accuracy, sensitivity and manoeuvrability, and, even today, the missile's ability to hit 115 mm/4·5 inch shells in flight is remarkable. Low level tracking capability in a radar-based system has always been difficult to achieve, and was initially tackled by reverting to visual guidance methods. However, later models of Seawolf now use dual frequency radar which overcomes the problems of interference close to the sea surface, and allows sea-skimming targets to be engaged in all weathers. Improved response time and the elimination of blind arcs has been achieved in the version of Seawolf fitted in the Type 23 (VLSW) (FIG. 8) by the use of two directors and vertical launch of the missiles; the latter development has provided a useful increase in maximum range, and removed the need for missile reloading in action.

FIG. 8—VERTICAL LAUNCH SEAWOLF (VLSW); A MISSILE BEING FIRED FROM THE TRIALS VESSEL

However, it is in the area of reaction time and multiple target handling that automation was found most necessary. Despite providing two directors and increasing the speed of the missile to shorten the duration of engagements, the detection, classification and decision-making time had still to be shortened, and this was done by eliminating manual action. Such an approach is nowadays regarded as quite normal, but was revolutionary twenty years ago.

What further improvements need to be made in AAW weapons in the next ten or twenty years? In that timescale progress is likely to be evolutionary as, for instance, directed energy weapons or rail guns will not be operational. Undoubtedly, for the medium to short range missile systems, the emphasis will be on multiple target handling capability, as this is still a limitation of today's more advanced systems. However, multifunction shipborne radars capable of combining surveillance with accurate tracking of many objects at once are now in service. This permits the consideration of simultaneous engagement, on any bearing, of multiple targets by controlling many outgoing missiles until they are within the range of their own homing heads. Furthermore, it will not be enough to view the ship's missile systems in isolation. It must draw its targeting and threat evaluation information from all sources; radar, infra-red, visual, electronic support measures (ESM), intelligence, and data link from other platforms. The system may then recommend or take the most appropriate retaliatory action, which may well not be a missile launch, but might be instead a soft kill measure such as jamming or the deployment of a decoy, or response by another platform. It should, by then, be routine to launch missiles for another ship to control, perhaps one with access to more accurate target data. Lastly, much greater attention to the ship services required by missile systems must be paid: trying to ensure that, with sufficient margins of capacity, their reliability and vulnerability are comparable; providing dedicated services where appropriate; and ensuring that they are all fitted in the same section in the ship.

Command and Control

It was announced with some gravity in the 1960 Report on Defence, as a significant indication of progress, that the new air defence system installed in the aircraft carrier H.M.S. *Victorious* contained nine thousand valves, compared with less than five hundred in the air warning system of *Illustrious* at the end of World War II. This was CDS (Comprehensive Display System), the world's first electronic system for recording, storing, classifying and displaying all data observed by the ship's radar; it was born mainly out of the need to cope with the higher speed of aircraft, leading to much reduced warning times for the defences. CDS used entirely analogue devices, valve electronics and capacitor storage permitting up to 48 aircraft to be tracked simultaneously, and was also installed in the first four COUNTY Class destroyers.

At the same time, machinery control in the COUNTY Class was individual to each machine, though by now operated remotely from a Control Room using pneumatics once machines had been started locally, and monitored using analogue sensors of various types. Some of these remote controls and sensors introduced significant time delays. Automation was confined to the boilers, using pneumatic meters to control fuel, feed water and air supply, in response to throttle demands; there was no thought of or need for amalgamation with weapon or sensor control.

Thirty years on, there is a significant convergence between Command systems, into which Air Defence systems have developed, and machinery control. Command systems turned to large centralized digital computers in 1965, but were limited for many years by lack of processing power, difficulties in extracting information from the radars then in service, and the price of electronic storage. The pace of change in the information technology field (IT) is now so fast that the Command system originally chosen for the Type 23 was cancelled in 1987, and the resulting competition is likely to produce one featuring colour displays and a real time distributed data base, connected by a triplicated combat system highway by which it communicates with the weapons and sensors. This kind of architecture offers considerable flexibility and resilience.

Meanwhile, machinery control underwent a similar revolution, the Type 23 being the first R.N. ship to have her machinery controlled by software. Items of main and auxiliary machinery are linked to a microprocessor-based local control and surveillance unit which communicates with a central console, using a serial data link for surveillance, but hard wiring for control. For the new minehunter, H.M.S. *Sandown*, development goes considerably further, with an automatic manoeuvring mode controlled by the minehunting Command system. For the first time in the R.N., machinery control has joined the Weapon System Data Bus to allow 'hovering' or change of ship's position to be an input direct from the Command system and to take place with no further manual action.

Thus, machinery and Command systems have converged and in some cases become united, but what need is there for further progress? In both areas there is a requirement to continue to reduce manning, and emerging technology can offer the potential for significant reductions. The more extensive use of Information Technology, in particular by providing intelligent man-machine interfaces, is the key to further progress. As the extent of artificial intelligence increases, some reduction in the training requirements for operators may be possible. However, there are other reasons for commonality of control in the future such as the necessity for warships to be manoeuvred automatically in response to threats, to minimize signature or damage, and to bring weapons or decoys to bear. Machinery control systems of the future will continue to be unmanned, with surveillance and control routinely passed to the bridge or operations room. The Command system will use Intelligent Knowledge Based Systems (IKBS) techniques, automated data fusion and sensor combination to assist the Command in rapid assessment of the tactical situation and in making the right decisions. Finally the Damage Control and Surveillance systems need to be added leading to a complete Integrated Platform Management System (IPMS) with distributed processing to reduce vulnerability and the amount of data to be transmitted; such a total system would permit the Command to have an accurate display of ship status in front of him at all times.

Atmosphere Control. Nuclear, Biological, and Chemical Defence (NBCD)

When mention is made of atmosphere control, the natural inclination is to think of nuclear submarines rather than surface warships. The former require atmosphere control because they have only infrequent access to a source of supply; the latter require atmosphere control because the source of supply may be contaminated. The need for protection in a toxic environment which includes NBC components led to the concept of whole ship pressurization, together with the control of entry and exit, without compromising the integrity of the citadel; this citadel is pressurized by a supply of specially filtered outside air.

The COUNTY Class were not the first warships with a citadel but the design benefitted from an Admiralty Board decision in the late 1950s that all future new construction ships were to have air conditioning fitted to operational and living spaces. Previously, air conditioning had been fitted to the main operational spaces and to a very limited extent to living spaces on an *ad hoc* basis. In the COUNTY Class the air filtration units were only used in closed down conditions; at other times separate vent inlets were used. However despite this impressive step forward, there remained a major problem in respect of the ship's ability to operate in a contaminated atmosphere. Because of the quantity of wild heat from the steam plant, it was impractical to close down (and shut off ventilation to) the steam turbine and boiler rooms for any length of time. Furthermore there were no air locks between the citadel and machinery spaces. Therefore in 1960, although a great deal had been achieved in terms of air conditioning, surface ships were still a long way away from total atmosphere control. However, the submarine world did achieve atmosphere control of steam plant machinery spaces at about this time, mainly by paying close attention to lagging requirements.

The Type 23 represents a further step forward for the surface fleet where all habitability air is drawn through NBC filters at all times. Air for galleys and laundries is still provided by separate systems which need to be closed down in assuming the citadel condition. This design does however reduce the number of ventilation terminals that need to be closed and achieves a reduction in the time and manpower required to achieve a satisfactorily pressurized citadel. Furthermore machinery spaces are now designed to be closed down, with the air being circulated through chilled water coolers in this state. The spaces are pressurized from the main citadel via air bleed valves.

Activities in the recent Iran/Iraq war have reminded designers that they must pay more than lip service to chemical warfare, and for the future it is clear that no unfiltered air should be taken into the ship at all (other than that required by the prime movers). Thus atmosphere control measures, well established in submarines to generate oxygen and to remove carbon dioxide, may well be a cost-effective option for the surface fleet. The degree of sophistication of this equipment will depend on the operational requirement in terms of the length of time the ship must remain closed down. In this respect the problem is identical to that in the conventional submarines of today.

In normal circumstances, the future escort will be supplied by fans with filtered air. Automatic chemical detection and warning systems are already in service; in future these could be used to stop these fans and close the vent openings automatically. The frenzied and labour-intensive activity, present today as a modern surface warship reconfigures its ventilation system from low threat cruising to a chemical alert state, will become a thing of the past.

Vulnerability, Damage Control and Fire Fighting

With a citadel and an effective pre-wetting system the COUNTY Class were very well equipped, for their day, to combat the NBC threat. However their capacity to deal with fire damage was eroded by two trends which lasted until the design of the Type 23. Firstly there was more combustible material on board, and secondly there were fewer system isolating valves, and even fewer capable of remote operation. Both trends were aggravated by the fitting of panelling, both on bulkheads and deckheads.

In the early development of the Type 23 it was considered that the normal NBC frigate measures could be compromised in order to reduce cost; for example there was to be no citadel.

Then came the South Atlantic conflict and some timely relearning of old lessons. The most important one was that much greater emphasis should be placed on the containment of smoke and fire in addition to the containment of flooding: in particular, the rambling ventilation trunking in the type 42s had proved to be a major weakness. The Type 23 had originally been designed to be divided into three sections by two fire containment bulkheads, and ventilation trunking did not cross these boundaries. It was decided however to increase the fire containment bulkheads to four, giving five sections (FIG. 9). This, in fact, required negligible change to the design, since the ventilation systems had already been grouped, as far as practicable, between main transverse bulkheads. The Type 23 has main transverse bulkheads watertight up the No. 1 deck to provide additional boundaries for the containment of blast, smoke and fire. Additionally, 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.

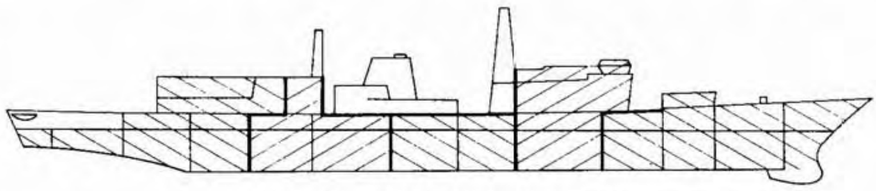

FIG. 9—TYPE 23 FRIGATE; ZONE BOUNDARIES

Thirty years ago the nuclear threat overshadowed that from smaller conventional weapons. The resulting damage scenarios led to the funnelling of resources into active protection systems, with less priority given to post-hit damage limitation measures. Interpretation of damage resistance of a warship is not simple, but the lessons of recent years in the South Atlantic and the Gulf have shown that significant improvements can be achieved, and at small cost if adopted in the early design stages.

To reduce vulnerability the zoning principle will need to be extended into complete weapon systems (i.e. sensors and weapons), in order to avoid total loss of ship capability from one hit. Staff Requirements for future weapon systems will thus need to embrace the necessary ship services. It is therefore axiomatic that these services will need to be reduced to a minimum, ideally to data, power and sea water only, all other services required by the weapon system being generated locally. it will then be for the ship designers to provide maximum protection for these three vital services.

To match the total zoning principle and the concept of a ship-wide IPMS, referred to earlier, particular attention will need to be paid to the systems for damage control and surveillance and for firefighting. This is also an area where there remains considerable potential for manpower reduction. An improvement is required in the scope of damage surveillance and control to reduce the dependence on manual techniques and voice communications. Sensors must provide more information, such as a rate of change of temperature rather than simply a change in temperature, and firefighting systems must be faster acting, more discriminating and demand less manpower.

For the future it will be as important to remember past experience as to incorporate new technology. When manpower and money pressures are exerted, it is only too easy to make savings—a euphemism for cutting corners—in the area of damage control.

FIG. 10—NAVAL HELICOPTERS: (FROM TOP) MERLIN, LYNX, WASP

Aircraft

Discussion of ships and their weapons cannot be considered complete without a mention of their aircraft (FIG. 10). Although not carried by the COUNTY Class, the Wasp helicopter was its contemporary, and was very widely carried in escorts of the period. The Wasp was the 'Morris Minor' of the aircraft world; simple, unsophisticated, with strictly limited capabilities, it remained in service for twenty-five years; its typical operating speed was 90 knots and its primary role was anti submarine warfare (ASW) in association with the ship's sonar.

The aviation department (or Flight) consisted of the pilot, an aircrewman and six maintenance ratings led by an experienced, highly trained and specially authorized chief petty officer. Exercises and operations were hard work and, often, complicated servicing was either anticipated before embarking, or deferred (where safe to do so) until the aircraft disembarked. Special deck handling and ship features included wheels which could be swivelled to allow the aircraft to pivot easily on deck and a special tie down swivel link to allow safe, unleashed pivoting prior to take off; and these arrangements made the Wasp a major step forward in helicopter operations at sea.

The replacement Lynx came into service in 1976 for use in the same role, but, by comparison, it is a vastly more capable aircraft, faster (120 knots) and more agile. Other improvements over the Wasp were the integral fit of radar, ESM, and the ability to carry Sea Skua anti surface ship missiles. An improvement over the Wasp is the Lynx's Harpoon/grid system to secure the aircraft to the deck, and, for all its sophistication, the Lynx Flight was increased by only one, a maintainer, although the aircrewman was upgraded to Observer.

The Type 23 frigate will initially be equipped with Sea King 6, but this helicopter will be replaced by a maritime version of EH101 (Merlin) in the mid 1990s. By 2010 Merlin will probably be undergoing its first major update, but the endurance with four torpedoes will be four and a half hours. Merlin is large; the size of four double decker buses (in pairs side by side and nose to tail) (FIG. 11). It is fitted with a fully integrated mission and aircraft

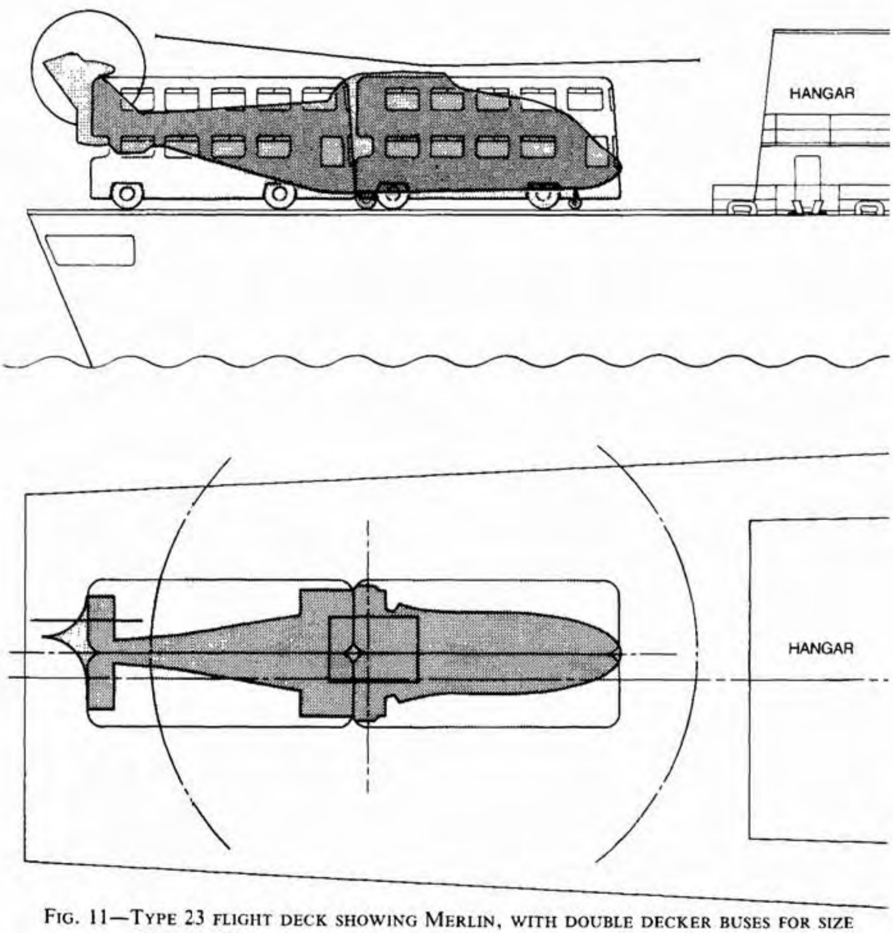

FIG. 11—TYPE 23 FLIGHT DECK SHOWING MERLIN, WITH DOUBLE DECKER BUSES FOR SIZE COMPARISON

management system using dual redundant data buses. Radar, ESM, sonics processing, communications and secure speech fits, datalink, a sophisticated navigation system using ring laser gyros in an inertial navigation system, together with Navstar global positioning system, and an active dunking sonar makes this an extraordinarily capable ASW platform. Future updates might include a passive identification device, colour displays and a missile fit.

Merlin is designed for reduced manpower, and hence has extensive built-in-test equipment, and health and usage monitoring equipment. The Flight will be one pilot, one observer and one aircrewman (note that the Sea King ASW helicopter needs two pilots) and nine maintenance ratings, a very modest increase on the Wasp and Lynx, considering that all front line servicing and maintenance can still be undertaken onboard. This is the first R.N. aircraft to be software dominated, and, as a yardstick, it uses twice as much computing power as the R.A.F.'s Maritime Reconnaissance Nimrod, or, more impressively, ten times that of the Tornado fighter aircraft.

Despite the great advances in the capability of helicopters in escorts over the period, manpower requirements have remained substantially the same; in effect we have had a spectacular rise in capability for the same manpower. Any reduction in manpower will have to be sought by development of, for example, fully automated refuelling and weapon loading systems. Notably, the powered handling system for the Merlin in the Type 23 requires no aircraft handlers on deck for ranging, take-off, landing on and stowing.

Organization and Complement

Automation over the last thirty years has already resulted in a considerable reduction in the need for manpower in the Royal Navy. However, manpower's continuing high cost and its declining availability are making further reductions a necessity, and automation is the way to achieve them. Recent studies have shown that savings of 40% in the complement of an escort are possible, but only with some radical changes in manning concepts, on top of extensive automation.

In the marine engineering field, a saving of over 50% is envisaged, by use of improved control systems and automated NBCD. Planned maintenance would largely be carried out in harbour periods by a dedicated support group. The Marine Engineering department would only operate the plant and carry out surveillance and repair, with the artificers confining themselves to the latter. Much of the engineering administration would also move ashore; interestingly, some of these measures have been common in submarines for years.

Rather smaller savings are foreseen in the ship support field, reflecting the fact that numbers here are already low. Techniques include the amalgamation of all offices and the reduction of paper; perhaps the preparation of food ashore, requiring it only to be heated subsequently, should be contemplated.

However, the warfare area is seen to offer the possibility of reductions in some fields by the full implementation of the user-maintainer role, partially achieved today, by Weapon Engineering personnel becoming increasingly involved in operations. Indeed a succession of studies on the relative duties of the Seamen and Weapon Engineer Branches have been conducted to define the future roles of each.

Command systems are a fruitful area for reductions, with more efficient plot extraction and automated data fusion eliminating many manual posts. There is also much opportunity for IKBS to ease the load on the Command by taking low level and routine decisions. Communications is another high user of manpower, where IT and auto-routing techniques will almost certainly yield significant reductions. ASW may be an equally fruitful area through development of auto-classifiers, and the grouping of equipment into comprehensive suites.

None of these manpower reduction proposals will however be cheap, and many require development of new techniques and equipment without necessarily enhancing performance—never an easy message to accept during the early years of R&D of equipment. Reliability and Maintainability (R&M) must also receive the appropriate attention at this early stage; the problem is addressed directly in the recent National Audit Office report which states that while the need for good R&M has long been recognized by the Ministry of Defence, the NAO examination indicates that R&M have consistently been sacrificed to performance, initial purchase cost and time. This lesson has to be learned.

Conclusion

Looking into the future is never easy, as witnessed by the remarks of a distinguished former Chief Naval Engineer Officer, Vice-Admiral Sir Frank Mason, who said in 1957 'At some future date, all warships, apart from minor ones, will probably be powered by reactors, and, as the cost of nuclear fuel falls, it will become economically attractive for commercial vessels'.

Pushed by the changing threat, pulled by lack of resources, and the recipient of a sharp reminder of the penalty of forgetting old lessons, escort design can be said to have kept its head above water over the last thirty years.

The future challenge will be more demanding as the manpower problem becomes more acute. Appeals for greater resources are unlikely to be welcome to the government and any lengthy period of lowered tension with the Warsaw Pact will reduce public awareness of the armed forces. The problem of creating greater military capability with fewer men with no increase in cost will thus have to be solved in-house. There is no option but to introduce even greater levels of automation, while at the same time maintaining a sensible rational awareness of the need for trained men to cope with unforeseen situations. This task will not be easy. Not only are the rule-writing problems difficult, the translation of these from theory to proven software and hardware will be formidable; events of seven years ago reminded everyone that final system proving when under attack is not ideal. All the greater the need therefore, when designing and manning 'The Automatic Warship', for well qualified and highly motivated naval engineer officers and ratings.

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