SOME THOUGHTS ON STRATEGY

AND ITS EFFECT ON THE DESIGN AND MAINTENANCE OF PROPULSION MACHINERY

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OPENING ADDRESS

(*by Captain Le Bailly*)

It is a great privilege for three ex-students of the old R.N. Engineering College at Keyham to present a paper in the Civic Centre of Plymouth, one of the 'Three Towns' for which our time at the College gave us such a great and lasting affection. To which it must be added, admiration for what has arisen from the ashes of the Globe, the Athenaeum, Nicholsons and the hostelries we knew so well. What feats of engineering might have been lost to the Royal Navy, indeed what you might have been spared today, if the citizenry and constabulary of this great city had been less tolerant of our escapades.

In attempting to analyse just a little of British maritime strategy and to draw from it any lessons we could apply to the design of propulsion machinery, we knew that we were treading a thorny path. Strategy is not a subject in which, in the past, engineers in general or naval engineers in particular, have been encouraged to dabble.

This vast complex of dockyards and this wonderful training machine at Manadon, and much else, are all pointed to one thing—the putting of a Fleet to sea with the most effective hardware, whether propulsion machinery or weapons and giving the nation thereby some return for its money and man-power. We therefore felt a considerable sense of responsibility in presuming to assert how part of this task should be achieved. We were also up against time and it soon became obvious to us that anything but a most superficial judgment on the interplay between strategy and the mobility of the Fleet in the more distant past would require far deeper research than we were able to devote to it; while in the more immediate past the impact of thermo-nuclear warfare has made necessary a complete rethinking of our strategy anyway.

True naval mobility, the ability to remain at sea for weeks or months or even years as so many famous sea Captains who sailed from this Port in centuries past knew it, is something we seem to have lost in the steam age, and only now are we realizing how far we have to go fully to regain it.

It was Fleet Admiral King in his report to the U.S. Congress at the end of World War II after that astonishing seaborne campaign in the Pacific who wrote 'Mobility is one of the prime military assets'. Perhaps in this country this doctrine of mobility in the shape of a quick reaction time, of long range and endurance, high speed, the ability to remain at sea without return to base for replenishment or man maintenance or material maintenance is something which has never received the close study it deserves. In postulating our 'Constabulary Concept' we hoped to draw attention to the way in which we feel true mobility, if this could be once more achieved, could be exploited on a truly integrated inter-service basis in support of the kind of national strategy we believe to be evolving.

As some who have read this paper have remarked, we have sidestepped nuclear propulsion on and below the surface, the hovership, m.h.d., fuel cells, and probably several other equally fascinating exotica.

In order to trace within our restricted time schedule the changing pace of machinery development we have had to ration our efforts to a catalogue of events which have taken the Navy in half a century from one which met what we would call a North Sea Strategy, with a fleet not really engined for far distant operations and which relied on the constant support and close proximity of the Royal Dockyards at home and abroad, to an Ocean Strategy demanding from the Fleet almost unlimited range and endurance, with little but 'afloat' support to keep it going at the end of a long supply line until the eventual return after months or years to the Home Royal Dockyards on the other side of the world.

So, as we see it, though the Navy had done some sort of machinery development testing at the Admiralty Fuel Experiment Station since the early days of the century and at the Admiralty Engineering Laboratory since the end of the first War (it could hardly be called research) it was not until 1944 that a number of steps were taken to put the development of the Navy's future machinery on a more rational footing. Efforts were made to interest the land boiler and turbine firms in naval machinery. The Admiralty embarked on a standard range of Diesels to reduce the enormous logistic problem with landing craft. The work at A.F.E.S. on combustion and at the A.E.L. on Diesel propulsion was stepped up very considerably.

In the next ten years a wide variety of development contracts were placed with industry for steam, Diesel and gas turbine projects ranging from the study of the best possible steam installation for immediate use in ships to a very ambitious development of a complex cycle gas turbine plant. Other forms of development contracts were aimed at improving methods of production, especially for instance, gear production. Committees were also set up to foster co-operation between the Admiralty and different industries. All this effort produced our modern steam machinery for frigates and destroyers, the Deltic engine for patrol boats and minesweepers, the A.S.R.I. engine for submarines and frigates, the G2 and G6 gas turbines as boost engines. Then of course the hydrogen peroxide fuelled submarines and the RM60 gas turbines were also both highly successful projects. In both steam, Diesel and gas turbine fields a great effort also went into producing electric generators and other auxiliary machinery.

It was at this point in time that to some extent we came unstuck. The emphasis in the requirements was all on reducing weight, space and fuel consumption which meant some tremendously ambitious designing well beyond the bounds of previous experience. The outbreak of the Korean War made speed inevitable and the step from the drawing board to the ship was taken too quickly. For instance the Y. 100 machinery design was started in 1949, the prototype set was delivered in 1951 and orders were placed for eight frigates to be built as fast as possible. Much the same applied to the Diesel-driven frigates.

The result was that when the early ships of these classes went on trial there were many teething troubles. And because of this hurry to get the ships to sea in the end it took nearly six years fully to fit the modifications found necessary from sea experience. But now this is done the *Whitbys* and the *Rothesays* and *Leanders* perform very reliably and are exceptionally easy to operate. The Diesel frigates with four engines geared to each shaft suffered also from serious clutch trouble between engines and gearing but once this was cured, as it quite quickly was, these ships too, quickly became known for their reliability.

In the boost gas turbine frigates we had learnt our lesson. H.M.S. *Ashanti* and H.M.S. *Devonshire* were completed well ahead of the subsequent ships of these classes and did extensive evaluation trials. We found out that gas turbines only reveal their secret troubles one after the other and throughout years of apparently trouble-free development they may keep a real stinker up their sleeve without revealing it. But during these evaluations at sea the snags were revealed and instead of all the early ships of the class enduring the same teething troubles the later *Tribal* Class frigates and *County* Class destroyers have been modified before completion and each ship has done better than her predecessor.

During this time, too, the Navy has got smaller, the ships more sophisticated and more expensive, while a rising standard of living ashore has meant better habitability aboard, only to be achieved by reducing the complement. We have managed, by design, to reduce the number of operators and the numbers on board are now determined mainly by the maintenance and servicing task.

The Fleet today faces unmentionable threats from weapons of devastating power and extraordinary accuracy which may be launched at it from near or far-off aircraft, from other surface ships or from the depths of the ocean. Answers to these threats have to be found, cost what they may. So fast is the progress of weapon technology that sometimes in the span of a ship's life of twenty years or so she is partially or wholly rearmed at least once or twice.

A constant tug-of-war exists between the very many excellent reasons for putting a wide variety of weapon systems in one biggish ship and the equal number of excellent reasons for dispersing our weapon systems in a smaller and more numerous fleet of escorts. But whichever course is chosen the optimum propulsion system will be very different indeed and generally it must last the life of the ship.

Even more difficult almost than money or the prophesying of strategy and tactics and technical equipment is the striking of the correct man-power balance. Quantity *versus* quality and the search for the right equation between numbers at sea and the numbers of uniformed and civilian technologists and technicians in the design and support echelons, are all problems difficult to define with any real precision. They are also matters of great public interest, albeit unhappily often uninformed interest. What is the relationship between the capital cost of the material built into a ship and the capital cost of manpower who design and finally put to work and maintain the material? After all, many airborne weapons of unparallelled ferocity carry no men. Is the number of men actually at sea any yardstick to the effectiveness of the Navy?

In the past so much of the globe has always been coloured red and in that red there have always been available friendly ports and bases and fuel and ammunition depots. Life from the logistic and maintenance and manpower aspect has not presented the operational problems it does today. Naval engineers, we think, have often not understood or more likely have not been allowed fully to appreciate these broad operational problems.

Indeed we, the authors, find it difficult to escape the conclusion (and perhaps we naval engineers have been to blame) that engines in the past have tended always to be too much the exclusive business of the engineers 'flitting through their ruddy tinctured twilight' and perhaps we have all been influenced too much by the apparent facility with which steam machinery can be tailored to fit the ship. Instead of, as we should, regarding the machinery as a most vital and essential military asset, as another weapon to be nurtured and bred from and developed fully to satisfy the operational environment and the operational reliability finally demanded of it. Perhaps we have all taken machinery too much for granted.

The 'Fascinating 'Fifties' provided us with a great variety of warship propulsion systems and with these we acquired wide experience. Steam is still the only suitable plant for the really high powers required in aircraft carriers. The development of the steam catapult, the very high demands for electric power for air conditioning machinery and the large demands for hotel services generally all favour large steam generators. The nuclear reactor is obviously a possibility for the future and is particularly suitable for a carrier where high power is required for flying on and off for a large percentage of the ship's time at sea.

For smaller ships there is a choice of steam, Diesels or gas turbines or a combination of either. Each case has to be studied.

It is clear that steam still has a future, but compared to Diesels and gas turbines the task it presents in a ship with its problems of accumulating water and steam leaks, of the many minor adjustments, of the hosts of drains, vents and so on which are apt to give trouble, make us long for a concentrated development of one set of steam machinery; so that it really is engineered like an aero engine and its troubles eliminated and its successors bred from it without everything being altered because of the difference in horse-power and shape of the next class of ship. We have no doubt that our steam machinery could be enormously improved for maintainability and reliability if the techniques now familiar in nuclear engineering for reducing leakages and for ensuring purity of water and above all, and we say this with all the emphasis we have, cleanliness in installation, were applied.

Our aim now must be to go 'nap' on the very minimum number of such systems which will give the Naval Staff a sufficiently wide spectrum of performance to cover their minimal need. Furthermore, in going 'nap' we must ensure, unless there are very formidable reasons for not doing so, that the machinery selected—this will apply particularly in the Diesel and gas turbine field—is developed from a line for which there is a large production need and which therefore will have big industrial backing. Alternatively, as naval requirements are unique in the field of steam, we may well have to develop one standard steam set right up from the drawing board (and pay for doing this properly) for naval purposes. By doing all this we shall not only concentrate the efforts of our diminishing technical manpower at Headquarters, which is good economic doctrine but we should also be enabled so thoroughly to test and develop the small number of chosen machinery systems—steam, gas turbine, Diesel or a combination of each—that though some ships may seem to be overpowered and some seem to be underpowered from the ideal power derived from the demands of the Naval Staff, the operational commander at least will be sure that what he has got is thoroughly reliable in terms of operational usage.

It was Mahan who said 'The need for a Navy stems principally from the possession of a merchant fleet and the need to ensure the merchant ships unhampered passage over the sea routes of the world', and Lord Fisher that 'The Army was a projectile to be fired by the Navy'. Both these statements are equally true now and so in the context of the world today our naval philosophy must be that the Navy fights *on* and under the sea and it fights *from* the sea. The latter category, including of course attacks on hostile territory by sea-based missiles, sea-based aircraft and amphibious forces.

We then, the authors of this Paper, visualize the three Services, under the umbrella of the deterrent, more and more playing 'the Constabulary Role', in General Hackett's words 'the orderly application of armed force', 'the management of violence'.

If this concept is valid then clearly the Fleet has to achieve a far higher degree of mobility than has ever before been considered possible in the steam age; and whether the mobility is above or below the surface is not really a relevant issue in the discussion.

With the Fleet we possess today and in the interests of the Fleet we shall possess tomorrow, we must continue a relentless battle for the precise definition of the really troublesome areas of machinery defects and failures. This is the job of the Ship Maintenance Authority, whose constant searching after facts and constant querying of any departure from pattern, together with a sense of understanding by the whole Fleet (for which we shall have to work) of the need for this sometimes painful probe, alone can give us the answer.

Constantly as we wrote our original Paper, and even more so as it has been discussed between ourselves and with our colleagues, it has been borne in on us how the high standard of design, development and manufacture, which the Navy has always demanded, is being pushed higher and higher by the pressure of technology applied to the limited war at sea in which we are now engaged. Failure to meet these demands will not be met by death as it is in an aircraft —at least not by sudden death—but it costs the sweat and tears of many devoted engineer officers, artificers and mechanics who are prepared to go to most remarkable lengths to keep ships operational—their great responsibility and pride, and one might add their great tradition also.

We, the authors, believe that it is because of the devotion of these men that we have got away with low development costs in the past; but the past is catching up with us.

Once the Ship Maintenance Authority has defined the areas of unreliability then these must be systematically removed by post-design work and subsequent machinery modification in the Royal Dockyards.

For the future Fleet, we reiterate once more we need to conceive a minimum number of propulsion systems which between them will cover the broad spectrum of Naval Staff Requirements, in terms of speed, noise, endurance, manpower and so on; and once conceived the design of these systems must be quite standardized and developed and tested to a degree of reliability comparable to that of the aircraft engine.

This, of course, may mean money. But it is our judgment (for what it is worth) that with proper concentration of technical effort on the combined problem of material and manpower that the cost will be no more than our much more diffused efforts today. And the final cost in terms of Fleet mobility, of operational usage, may well be less.

Finally, may I repeat a paragraph from our Paper, which seems to us to be terribly important:

> A strategy is a policy which, with the world moving at such a pace, can be changed if not overnight, then certainly far more quickly than machinery

can be designed and developed, and ships built and deployed. The thoughts and ideas of Statesmen and Governments can be translated into words, so fast; the concepts of the scientist and the engineer take years to see the light of day. Because of this, it is vitally important that the scientists and engineers are in close touch with the strategists. Major new technological concepts must be grasped quickly, brought to the notice of the strategists, and their evolution must not be delayed by preoccupation with minor details, or by mere indecision. We naval engineers must ensure that the technical instruments of our maritime strategy are the right ones and are ready on the day. To do this we must think about these things, know about them and discuss them. The balance between what is required strategically and what is practicable technically and within our resources, must be struck at an early stage and we 'the hardware men' have a tremendous responsibility at that moment.

This finishes my opening gambit. The whiz kids on either side of me need little introduction. Captain Raper has been involved in every advance in propulsion machinery, especially steam propulsion machinery, in the last 18 years. Captain Douglas-Morris has just established the Ship Maintenance Authority to which we in the Directorate of Marine Engineering now look to keep us on the road which has been cleared for us by our predecessors, and along which we are travelling towards the simple goal, which we believe is one of uncompromising sanity, which we see quite clearly and which we have tried to indicate in this paper. The goal is an absolute minimum variety of propulsion and auxiliary plants, supported wherever possible by a commercial market, tested and developed to a degree of reliability which will maximize the usage and minimize the need for manpower and forward bases.

THE EARLY YEARS

'Strategy', wrote Lord Fisher, 'should govern the type of ship to be designed. Ship design, as dictated by strategy should govern tactics. Tactics should govern details of armament'.

The primary role of the Royal Navy in the Fisher era was the defence of our island and our main Battle Fleet was designed specifically with this strategy in mind. For support and maintenance it rested on the Home Dockyards and abroad there was that great chain of coaling stations and dockyards stretching around the world. The tactics were those of Trafalgar and with the lessons of Tsushima in mind, those great ships, the *Queen Elizabeths*, were designed to burn oil so that they might have both the speed to 'Cross the Enemy's T',* to throw his van into confusion and batter it with their 15-in. shells.

The *Queen Elizabeths* in fact, perhaps even more than their elder sister H.M.S. *Dreadnought*, bridged not only the era from sail to steam tactics, for they were in the forefront of the battle in the Second World War, but also the change from coal to oil. No technical decision in the whole history of the Royal Navy stands out so starkly as this one. To make the Royal Navy 'on which', to quote the old Articles of War, 'under the good providence of God the wealth, safety and strength of the Kingdom chiefly depend', entirely and completely dependent itself on a fuel brought from the sand of a foreign country thousands of miles away, makes the decisions which today have yet to be taken on surface nuclear propulsion seem comparatively prosaic. Perhaps only two great men acting in concert could have persuaded the country that

*This was the tactic employed by sailing ships having the weather gauge, by means of which they could bear down on the enemy's line and throw his van into confusion, raking the enemy leading ships from bow to stern with broadsides, to which there would be little reply.

the decision was a right one. Writing of it afterwards Sir Winston Churchill said 'The oil supplies of the world were in the hands of vast oil trusts under foreign control. To commit the Navy irrevocably to oil was indeed to take arms against a sea of trouble! Wave after wave, dark with storm, crested with foam, surged towards the harbour in which we still sheltered. Should we drive out into the teeth of the gale or should we bide contented where we were? Yet beyond the breakers was a great hope. If we overcame the difficulties and surmounted the risks, we should be able to raise the whole power and efficiency of the Navy to a higher level; better ships, better crews, higher economies, more intense forms of war power—in a word, mastery itself was the prize of the venture. Forward then.'

One of the prime reasons for turning the Fleet to oil was instantly forgotten. This was its ability to fuel from accompanying tankers; so that thereby the Fleet at sea could be reinforced by perhaps a quarter, the proportion usually coaling in harbour. The Royal Navy dallied 30 years before it fully re-learnt this lesson at the hands of a younger Navy when, in 1944, it joined with the vast and newly built United States Pacific Fleet. Nevertheless the old coaling stops provided the engineers of the day with a regular pause in steaming which allowed them to deal with urgent defects.

Technically no very clear picture emerges from the first Great War. Steam was still saturated; the craftsmanship of the artificer and the brawn of the stoker carried the Fleet through despite the difficulties of 'wrapperitis' (cured by making water drums cylindrical) 'condenseritis' and of life in general in a coal-fired boiler room. They were a race apart those men and in the face of almost unbelievable hardship and technical difficulty achieved and retained, with nothing but their tools and their skill and sheer guts, a standard of availability and usage which, faced with the same conditions, few would believe possible today. The *Western Daily Mercury* of a few years before had this to say: 'But he had probably never seen, amid their proper surroundings the men whose labour lies deep down in the steel caverns of the warship; who flit like spectres amid the ruddy tinctured twilight; always watching the pulsation of the leviathan's giant heart, with fettered death ever lurking at their elbow, and ever striving to burst the bonds that restrain his devastating spirit. These Engine Room Artificers without whom in the hour of urgency the Naval Engineer would be as helpless at his post as the traditional boy standing on the burning deck.'

The ships and machinery of those days were to a large extent produced by the inspiration of a comparatively few outstanding men, like Sir Charles Parsons and Sir Alfred Yarrow who were not only inventors in their own right, but able themselves to encompass most of the available knowledge required for the design of ships and their machinery. Thus marine engineering and the problems of electricity generation ashore advanced hand in hand under their inspiration.

THE 'TWENTIES AND 'THIRTIES

What Captain Roskill has called 'The Uneasy Interlude' provides one of those disastrous periods in history which have so often succeeded any great struggle, when the nation turns its back on the Armed Forces in general, and the Royal Navy in particular. As Captain Roskill goes on to say: 'Yet hardly was the ink dry on the treaty of peace before the victorious nations embarked on a whole series of diplomatic negotiations which in the sum resulted in Britain sacrificing her ancient maritime supremacy and accepting the limitation of her naval armaments—and because (the treaty) was linked with complicated rules governing the displacement of major warships and the calibre of their armaments, it produced for the Admiralty a large crop of difficult technical problems.'

Finally, in 1930, the Treaty of London extended the limitations on major warships to cruisers, destroyers and submarines and in 1935 an agreement was made with Germany that finally allowed them to build submarines without restriction.

Machinery Design up to the Second World War

The Admiralty policy understandably was still to use materials which could be worked in most ships' workshops. Almost any spare part could be made on board and it was a source of pride to engineer officers that their spare gear boards were purely ornamental with the spare parts highly polished show pieces. Worn parts of machines were replaced by new parts manufactured in the ship's own workshop. (This saved the Admiralty money and was thus not discouraged.)

Boilers were still required to be cleaned after every 21 days' steaming (a 'day's steaming' being defined as any day on which the main feed check valve was open); which provided a programmed and mandatory pause wherein the machinery could be maintained. Because of the need to save money and the resultant restrictions on the fuel allowed to the Fleet each year, the boiler cleaning period did not provide an intolerable restriction on operational or exercise programmes and so the need for it was never seriously questioned.

These years saw the growth in the country of a highly competitive engineering industry associated with power station machinery. But they saw also the virtual separation of the 'sea' (marine engineering) and 'land' (power station) industries; while within the ship-building industry the engineering and ship-building sides within individual firms engaged in a tussle for influence, not always with happy results.

With the expansion of these technologies it was no longer possible for one man to grasp the whole field of design and production. The play which the inventiveness of the early engineers had had in an expanding economy was thus no longer available to marine engineers. Grass was growing in the ship-yards and the young and enthusiastic were leaving the shipbuilding and marine engineering industries, never to return. The Admiralty had no money to spend on research and development.

At a period therefore when the web of treaty conditions required great technical enterprise to enable maximum use to be made of the ship displacements to which we were confined, there was no money available to stimulate this enterprise or to encourage experiment.

The separation of 'land' and 'marine' industries prevented the natural flow of ideas from power station developments into the Navy and in the interest of the strictest economy the Admiralty concentrated on reliability as the first requirement for the designs of its new machinery. This resulted in development being only very gradual as each new class was built with machinery based on the previous class, but pushed a little further in temperature and pressure.

At the start of the Second World War steam conditions of 400 lb/sq in. and 700 degrees F. though first used in the 'twenties had, by now become general. The three-drum boiler was almost the only design in use, with air preheaters in large ships. The closed feed system was an inter-war development but otherwise little had changed fundamentally.

Nevertheless against the yard-stick of the first World War, progress looked encouraging. As an example H.M.S. *Queen Elizabeth*, her direct drive turbines and 24 boilers installed at the beginning of the First War was re-engined and re-boilered in 1939 with geared turbines and superheated boilers with a saving of weight of 50 per cent and space of $33\frac{1}{3}$ per cent, while her endurance at 10 knots was trebled. At the same time recruiting for naval artificers was highly selective and the generations of engineer officers brought up in battleships and cruisers before going as 'Chief' of a destroyer knew all the idiosyncracies of the machinery they operated.

Yet so short was money for fuel at this time that battleships were keeping steam in harbour for auxiliary power with natural draught and a temperature of 160 degrees F. in the boiler room. Cruisers were limited to thirty-five days sea time and destroyers to forty-two. Under these conditions it was not surprising that maintenance presented few problems. Even the Spanish Civil War and the Abyssinian War provided no real challenge: there was still plenty of maintenance fat to be run off.

The outbreak of war with Germany, however, tested to the limit the machinery and the men who operated and maintained it. Every day in harbour was necessarily begrudged and many weaknesses in design hitherto unsuspected were brought to light. It was perhaps only because of the long experience of regular engineer officers and the Chief and Petty Officers and the very intimate knowledge they possessed of their machinery that the Navy was able to keep at sea with such remarkable reliability, under operational conditions which the designers had never contemplated.

But once an ocean war was forced on them in the Pacific the short-comings of our ships for this role became fully manifest and they were almost insuperable.

LESSONS OF THE SECOND WORLD WAR

What could be done was done and when, one day, the full story of the engine and boiler-room crews of British carriers and destroyers in the Pacific comes to be written it will tell a tale of endurance rarely equalled. But endurance and courage were not enough and nothing could conceal the fact that the application to its propulsion machinery, by the United States Navy, of the latest engineering developments in 'land' practice as regards steam conditions, materials and manufacturing techniques, had given it what was generally regarded as a 20-year lead in operational performance for ocean war, over the Royal Navy.

The second operational advantage possessed by the U.S. Fleet was their ability to fuel at sea. The Royal Navy soon learnt to do this too but the cost in fuelling hoses flown forward by the Royal Air Force from Australia was prodigious and the supply nearly ran out!

The third great advantage was the introduction of boiler water treatment which allowed boilers to steam without internal cleaning for years,rather than 21 days, When the actions of the junior R.N. officers who procured 'Boiler Compound' from the U.S.N. with that greatest of all international currencies—Scotch Whisky—were finally accepted and the use of boiler compound was introduced officially into the Royal Navy the whole traditional maintenance pattern of the Fleet was thereby upset. Only now, 20 years later, are we beginning to find an alternative pattern which will produce an acceptable answer.

THE MIDDLE AND LATE 'FORTIES

At about that moment, in the middle forties, when Midshipmen (A), as they were called, were crowding into the R.N. Engineering College, Manadon, to be trained to maintain the aircraft in our new great fleet of carriers, the Engineer-in-Chief's Department were turning towards the problems of introducing steam temperatures of 850 degrees F. and pressures of 650 lb/sq. in., low alloy steel boiler drums, stainless steel boiler casings, small high-speed steam turbines for main engines with heavily loaded double reduction gearing and turbo-driven auxiliaries of exceptionally high revolutions, geared and using the full steam temperature. The demands made on the engineering designers stressed increasingly the need to design for a very large cruising range within a minimum total weight of machinery and fuel.

Dependence on Industry

The Engineers-in-Chief of the Fleet and their successors the Directors of Marine Engineering have always had a very clear and distinct policy of dependence on Industry. Before the Second War the 'industry' was the traditional shipbuilding and marine engineering industry.

After the war it was recognized that the Royal Navy needed to make use of all that was relevant from the whole of British, and if necessary, foreign industry. For this purpose the Yarrow-Admiralty Research Department was set up, originally to survey the whole field of engineering development and to recommend to the Admiralty a 30,000 s.h.p. installation which would really represent the best the country could do. This activity was extended to many subsequent projects along similar lines. Y-A.R.D. does not compete commercially and works under the control of, and in the closest co-operation with the Navy Department, constantly studying the requirements for naval machinery as they develop and investigating the feasibility of all the conceivable combinations of machinery that may fulfil them.

This period, which we might well call 'the Fascinating 'Fifties', was one in which the Navy gave itself a prodigious shake.

While the officer structure of the Navy, the organization of the Admiralty Departments, the Dockyard organization and many other aspects of the structure of the Royal Navy and its support were being questioned and revised, sometimes dramatically, a programme of research and development in steam, Diesel and gas turbines for ships' propulsion was steadily pushed forward by the Admiralty, based on development contracts with industry. While other aspects such as the whole fuels and lubricants policy of the Navy was subjected to close scrutiny by a committee in which the oil companies have given and are still giving immense help.

So, from Abyssinia to Korea after nearly twenty years of war, in that period when historically, as we have said before, the Navy knows itself to be in for a period of neglect the Board of Admiralty quietly worked away at refurbishing the Royal Navy and making it ready for whatever strategy may evolve from the rising crescendo of world affairs.

Naval Propulsion Engineering in the 'Fifties

Development contracts were placed for various types of gas turbine, steam turbine and Diesel engines. Some flourished, some were dropped, but a great insight was gained into what was involved in the application of various engines to naval purposes. The most difficult aspect of this was the ever present threat of having to stop development after much work had been done and sometimes even after a successful prototype trial, because the requirement for such an installation had disappeared. This was the era when the Deltic engine, the G2 and G6 gas turbines, the RM 60 gas turbine, among others, were developed and the Admiralty Standard Range of Diesels was selected. Y.100 steam machinery for frigates and boost gas turbine with a basic steam plant, were evolved and fitted in the *Whitby* and later classes of frigates and the guided missile destroyers, respectively, and a basic prototype for advanced steam machinery was built and tested at Pametrada.

A characteristic of all these developments was that none cost more than £5 million; chicken feed by aircraft standards. The numbers built varied from two to about two hundred, but never much more. The results were incorporated in new classes of ship designed in the early 'fifties.

For the steam frigates the design conditions were very severe. Displacement was limited to achieve manœuvrability and this could not be met, and a worthwhile weapon load provided, unless the weight of machinery and fuel was reduced by about 25 to 30 per cent compared to our war-time machinery. Hull weight and the weight devoted to accommodation were already almost at an irreducible minimum and so the balance had to be divided between the weight of providing mobility and the weight of providing communications and weapons. If one was increased the other had to be reduced.

Space, too, was scarce and margins had to be drastically cut; while the demand for longer range was insistent and overwhelming.

All this has given us the Y.100 series of machinery installations in the *Whitbys*, the *Rothesays* and their latest successors, the *Leanders*. The challenge was formidable indeed and of disasters, or rather of 'crumbles' (now the current jargon) we had our fill. But out of all this has come one of the most compact and reliable machinery installations in the history of marine engineering.

The anti-aircraft and aircraft-direction frigates were engined by the Admiralty Standard Range I Diesel engines and the *Ashanti* class frigates and guided missile destroyers with the G6 boost gas turbine. The latter were powered by a basic steam plant evolved from the advanced steam prototype installation tested at Pametrada. Both classes are now at sea and the experience is building up.

The Lessons of Development Experience

These plants were designed mainly to meet the requirements of low weight and space and good economy at low powers. In the Diesel field the logistics of spare parts and ease of maintenance were given much consideration.

Experience has shown, however, that the prototype testing was not sufficient, within the terms of time and finance allowed, to produce complete reliability of all the components in the early ships of each class fitted with any of these installations. Nor was it possible to study the maintenance required or to produce the modifications needed to reduce maintenance, before the design and production of the first few ships were already committed. The statistical evidence of weaknesses as a result of experience at sea takes several years to build up so that we became once more dependent on the engineers at sea to deal with the early difficulties of new types of machinery and to try and set a pattern for operation which allowed the necessary time for servicing and maintenance, while ensuring reliability for the maximum sea time.

This sort of dilemma is particularly evident in any machinery developed specifically for the Navy and having little commercial attraction. The wisdom of adopting standard commercial engines, such as we did in the lower horse-powers of the Admiralty Standard Range of Diesels has been amply proved by the wide operating experience quickly becoming apparent.

On the other hand through its own development the R.N. now has available a background of unique experience with various types of high horse-power machinery developed specifically to meet warship requirements. On these development decisions required for the future may be based with far more confidence than has been possible in the past, and decisions moreover which could never be made by extrapolation from the much lower powered installations needed for the Merchant Navy.

In the meantime we have become a Navy predominantly of small ships. As the cost of each one steadily rises with the sophistication of weapons and equipment generally, the number the nation can afford to build is correspondingly reduced. And yet the role the Royal Navy is called on to fulfil offers no corresponding reduction in the tasks to be performed. The result is that every ship must be used to the limit and, as in the war years, it is imperative that time for maintenance or refit is reduced to a minimum.

This has brought about a careful study of the maintenance task, and a much greater emphasis on this aspect of the design and development of machinery.

The designs of the 'fifties paid much attention to reducing the need for skilled operators and the introduction of automatic controls goes a long way to achieve this. But ships still have to carry a high proportion of their maintenance staff with them and there is a pressing need to reduce this number, as well as to reduce the time in harbour needed to carry out their tasks. More will be said of this later, but in the meantime the development of existing designs is being pursued with this object and a new Auxiliary Machinery Test House is being built at the Admiralty Fuel Experimental Station at Haslar to study reliability and the means of reducing maintenance.

THE DESIGNS OF THE 'FIFTIES AND MAINTENANCE

In the process of developing machinery to meet the modern needs the type of maintenance required has inevitably been changed.

Steam Machinery

Boilers remain one of the principal maintenance loads but not because of the need to clean them internally; the problem is more one of external cleaning and the upkeep of the mountings. This external cleaning now takes the form of water washing and the design of the boiler can have a very great influence on the effectiveness with which this is achieved. Successive designs have allowed larger access passages in between superheater headers, between superheater tubes and generator tubes and by lanes in between banks of generator tubes. All these have helped the task of maintenance.

The old trade of naval boilermaker, those tough and faithful artificers, is now dying out. The whole of the oil-burning equipment and the casing and general fittings require a far higher standard of accuracy of fitting by a skilled fitter, equally tough and faithful without doubt, but lacking perhaps that robust vocabulary which helped the boilermaker to endure the appalling conditions under which he so often worked.

As with the sophistication of the boiler, so with the rest of the steam plant; old skills are changing. The traditional type of fitting work where there was little difficulty in finding out what was wrong but a good deal of difficulty and tedious work in putting it right has given way to the more precise diagnostician's work of finding out what is wrong with a boiler automatic control or pump governor and repairing it by the replacement of the faulty part.

The activity of planned maintenance thus almost becomes one of inspection and replacement rather than demanding much skill of hand in fitting new parts. We say 'almost' advisedly for the Navy has not yet been able to dispense with a high standard of skill. It has been found, time and time again, that the spares produced do in fact require very skilled matching to a machine to make them fit properly. The standard of interchangeability achieved is still inadequate for the requirement.

We referred earlier to the compression of machinery into small spaces and this has a cumulative effect on the number of man-hours needed to refit the machine; so often there is a need to clear away extraneous piping before the offending part can be reached. It is fair to say, however, that steam pipe leaks, the major cause of most all-night work in the last war are now, thanks to new jointing techniques and welding, no longer a problem.

Diesel Propulsion

For the aircraft-direction and anti-aircraft frigates we adopted Diesel propulsion. We went to the Admiralty Standard Range I Diesel putting four engines totalling 8,000 s.h.p. on to each shaft of a two-shaft class. Diesel enthusiasts had for long advocated this measure allowing (as it was thought) each engine to be hoisted out of the ship and replaced after a certain number of hours thus reducing to a minimum the time out of action required for maintenance. When the ships came to be designed and built however it was found impracticable to make these A.S.R. 1 engines removable from the hull and they subsequently presented a nightmarish maintenance problem with (including the generators) some 170 cylinders to be maintained in each ship. At periodical refits the number of parts which have to be examined causes a formidable organizational problem for the dockyards. These ships have, however, proved very popular among Captains because of the reliability and the number of alternative engines available if any one of them breaks down or runs out of 'hours'.

Gas Turbines—the Boost Concept

War and peace-time experience showed us that a warship was needed to steam at full speed or near full speed for only a relatively short period of its life. From this we derived the idea of a base steam plant for up to 25 knots boosted to maximum power whenever necessary by gas turbines.

This arrangement offers a long endurance and also an independent power plant which gives the ship a quick 'reaction time' be it needed for weather, by an operational requirement to get somewhere quickly while the steam plant is being maintained, or in the event of a sudden enemy attack.

Experience with these two types of machinery in a single ship is not yet sufficient to yield firm conclusions. The initial reaction of ships' officers is, however, that the gas turbines provide far fewer maintenance problems than the steam plant and, apart from fuel consumption, are thoroughly suitable for naval purposes.

The Last Decade

All these then were the products of the 'Fascinating 'Fifties' and we must not omit, though we cannot describe the vast technical effort deployed on nuclear submarine propulsion.

For some of this time the very need for a Navy was doubted. For two-thirds of the time there was a shipbuilding boom and warships could not be built either economically or quickly. The more obviously attractive weapon systems with their insatiable capacity for money put the more mundane needs of propulsion systems in the shade.

The miracle is not that the Board of Admiralty managed to hold some sort of balance but that they also set on foot so many internal revolutions, while at the same time keeping the Navy in business in every phase of maritime war, including almost every known method of ship propulsion.

Looking back on this historic decade will give naval historians of the future a wide field of research and it may be that decisions taken in this period will be regarded as among the most momentous in the Navy's long history.

THE FUTURE

Towards a Maritime Strategy for the Future

And so from the present we turn to the future. What maritime strategy shall we pursue and how shall we design ships and machinery to make that strategy work? And here we run headlong into difficulty. A strategy is a policy which, with the world moving at such a pace, can be changed if not overnight, then certainly far more quickly than machinery can be designed and developed, and ships built and deployed. The thoughts and ideas of Statesmen and Governments can be translated into words, so fast; the concepts of the scientist and the engineer take years to see the light of day. Because of this, it is vitally important that the scientists and engineers are in close touch with the strategists. Major new technological concepts must be grasped quickly, brought to the notice of the strategists, and their evolution must not be delayed by preoccupation with minor details, or by mere indecision. We naval engineers must ensure that the technical instruments of our maritime strategy are the right ones and are ready on the day. To do this we must think about these things, know about them and discuss them. The balance between what is required strategically and what is practicable technically and within our resources, must be struck at an early stage.

A National Strategy

So we turn to the many threads which must be woven together into a national strategy.

War, the Prime Minister has said on several occasions, is no longer a valid act of deliberate national policy. And perhaps we may hope that within the next decade even China will come to accept such a doctrine. But even then little will have happened to lessen tension between man, or the causes of conflict between the multiplying sovereign states. A wholly communist world will remain the aim of Russia and China, and communist 'blackmail' in a wide variety of guises, will constantly increase. Thus the West will continue to need a really credible deterrent to ensure that any attempt to start a world war remains an irrational act, and also to make it plain to any who might succeed the existing sophisticated leadership in Russia that an attempt to revert to the old Stalinist dogma of the inevitability of war carries with it the certain risk of world extinction.

Thus the West needs a first strike and, more important, a second strike capability which is palpably real. In Europe, too, where more than anywhere the situation will remain tender, there is a need for sufficient land and air forces to ensure territorial integrity without the necessity for an immediate nuclear exchange, whether tactical or strategic.

But it is in the countries outside Europe that the greatest danger threatens. If the Free World is to escape gradual erosion, it must be able to avoid the *fait accompli* of communist occupation. It will always be impossible to protect every area locally; but the very minimum aim, by political means and by aid, must be so to nourish and sustain the local defences that the possibility of a cheap communist victory is excluded.

In the Middle East and in South-East Asia in particular, the Communist bloc with its inner lines of communication is always able to concentrate its manpower and material against countries which are militarily weak.

The Meaning of Limited War

General Hackett has said: 'Total war we have to avoid. But acts of organized violence between groups of men which we are unlikely to be able, entirely, to prevent, we must do something about.' And again, ' . . . situations are easily conceivable in which the only hope of avoiding something worse may lie in taking a hand in it. We may well be working towards a position in which the main purpose of the profession of arms is not to win wars but to avoid them; that is to say, by timely warfare to lessen the risks of general war. The chief function of the armed forces becomes the containment of violence. The function and duty of the military professional is the orderly application of armed force . . . his duty is to develop his skill in the management of violence.' 'We are moving', suggests General Hackett, 'towards what Janowitz called the Constabulary Concept'.

Military Implications of the Constabulary Concept

Possibly the most sensitive area and the most difficult for the Royal Navy is the Indian Ocean and South-East Asia. A force the size of the U.S. Seventh Fleet, in conjunction with the navies of India and Pakistan, could utterly dominate the whole Indian Ocean and the Bay of Bengal, while at the same time fulfilling the Constabulary Concept. But such a force is beyond the financial resources available to the United Kingdom today.

If, then, General Hackett's proposition is applied and the U.K. sets about providing an effective Constabulary Force some more precise idea of what can and cannot be accomplished needs to be spelled out. The Constabulary Force is by definition a highly mobile and relatively lightly armed force which can provide an armed garrison in some troubled area almost at the drop of a hat. Behind it lies a sufficiently massive and quick follow-up able to stabilize the situation for as many hours or days as possible while diplomacy tries to settle the issue. The greatest weapons of the Constabulary Force, in fact, are speed and resolution. Whatever the implications in the field of the weapons with which our ships are to be equipped it is clear that the ability to remain at sea for prolonged periods, to possess a quick 'reaction time' and to be able to concentrate quickly at the trouble spots is more necessary now than ever before.

The conclusion which we, as authors of this Paper feel to be irresistible is that only nuclear power could really satisfactorily enable us to station a maritime Constabulary Force permanently East of Suez. But however clear that may be for the late '70s and '80s too much time has been lost and our task as marine engineers is to design a Fleet which can operate satisfactorily in the Far East in the late '60s and the early '70s with conventional, not nuclear power.

Main Technical/Operational Guide Lines

The guide lines on which we must march are:

(*i*) Long Range
(*ii*) High Speed
(*iii*) Silence
(*iv*) Reliability
(*v*) Minimum Skilled Manpower

and for the weapon services and hotel services we need to cope with heat removal, advanced hydraulic and control problems, heavier aircraft at higher landing speed and a multiplicity of smaller but difficult problems associated with these functions. But above all, for this is surely the one constant demand from our political masters, our small but expensive Fleet must *keep going.*

THE WAY AHEAD

The field is now so wide and the possibilities of different power units so extensive (and in many cases so expensive) that a comprehensive and factual survey was undertaken by the Y.-A.R.D. This has given us several weighty volumes. It does not lay down policy, neither does it make decisions. It collects, evaluates and compares information on the various means available for driving ships through the water at the speeds and with the endurances likely to be required by the Naval Staff.

The Aircraft Carrier

Very broadly for large ships such as aircraft carriers the steam plant is best and of course the catapult requirements, the need to shoot heavier and ever heavier aircraft off the deck, enter very closely into any consideration of this problem, but as to whether the steam is made by nuclear or fossil fuel that is another story altogether!

Small Ships

For small ships the choice is wide open and here strategic considerations, manning and welfare problems and the varying views of the operational commander need very precise analysis before any reasoned judgement can be arrived at. But again through the mass of detail a few signposts stand out:

(*a*) Where possible there must be simplification of units and installations. Where complexity is inevitable there must be complete reliability.

(*b*) Units must be accessible for maintenance.

(*c*) Engine and sub-assembly removal must be allowed for.

(*d*) Proper shore testing of components and endurance running of auxiliaries must be allowed for, both to establish reliability and to study and reduce the maintenance task.

Steam

The development of the fullest reliability during extended periods between refits is a clear requirement as is the need to reduce maintenance. For this it is essential that we should develop further what we know to work, and machinery with whose strength and weaknesses we are familiar.

At the same time there is a corresponding need if we are not to be left behind in the technological race to embark on a longer term and consistent development policy for steam plant of a much improved type. The possibilities of closed cycle, completely sealed water and steam circuits have been demonstrated in the nuclear engineering field. The field of fossil fuel combustion has still far to go and there are many other possibilities of injecting the most modern engineering techniques such as the use of fuel cells into the field of marine propulsion.

The price of reliability and reduced maintenance may well be, however, that we must abandon the old idea that steam machinery can be tailor-made to any horse-power and any shape of compartment without major development work. The steam installation of the future, if it is to succeed in making a substantial advance in maintainability may well be as rigidly confined to a given horse-power and shape as the Diesel engine or the gas turbine. Although marine machinery can never be fully proved ashore the time interval between the conception of a new design and its adoption for a new class of ships must allow for adequate shore testing to iron out the difficulties inherent in every new design. Ideally it should also allow an interval while it is proved at sea.

Diesels

There has been, at last, a great upsurge of improved designs in the Diesel industry to meet commercial demands and there are now in existence or being developed a range of engines which appear to have attractive features for naval main propulsion units; notably where long endurance is concerned or in conjunction with gas turbines where long endurance and high speed are required. Diesels tend to be noisy however and raise minimum speed and manœuvering problems.

Gas Turbines

Fifty years ago Admiral Lord Fisher wrote to Sir Charles Parsons 'What breaks my heart is that you can't see your way to associate the turbine with the principle of internal combustion propulsion.' The Royal Navy now has major warships at sea with gas turbine propulsion. The 'G' series fitted in our latest frigates and guided missile destroyers have fully achieved the target we set ourselves, both as a boost for high speed operation, and in their ability to get the ship under way quickly they have been most successful. As a prime mover, however, they have a high specific fuel consumption. The development, *ab initio*, of an economical naval propulsion gas turbine would be very costly as well as time consuming. Inevitably therefore we have cast about for gas turbines developed for aircraft which could be made to stand warship conditions. Studies are going on in this field and the possibility of waste heat boilers in conjunction with gas turbines is also under investigation.

It is not possible to tailor the power of a gas turbine to suit a particular ship and therefore it is important to make the right choice before we embark on the considerable task of 'marinising' a gas turbine initially designed for the very different conditions in an aircraft. The great advantage we foresee, if we can pick the right aircraft engine, is that there will be a background of experience and the backing of a highly expert industry with unparalleled testing facilities behind its production line.

Surface Nuclear Propulsion

Singly or collectively we should be delighted to debate this much debated subject. But in view of the rather fluid situation at the time this Paper is being written, it is perhaps better that we should refrain.

As we see it surface nuclear propulsion is an ideal mode of propulsion fully to implement the 'Constabulary Concept' and if such a strategy is to be properly served then we should procure suitable reactors wherever they exist.

In all these prognostications, however, the essential need is that the upkeep task should be in the forefront of the minds of the engineers concerned with design and development.

The Upkeep Task

Sir Dudley Pound once wrote to Sir Andrew Cunningham: 'It is only politicians who imagine that ships are not earning their keep unless they are rushing madly about the ocean.' But today it is abundantly clear that in the interests of tranquillity and of peaceful investment in the economy of the littoral nations surrounding the Singapore, Darwin, Cape Town, Aden quadrilateral, more and more ships are needed to be kept at sea in this, perhaps the hottest and most trying sea area of the world. We must do it within a rigid budget of money and men and, to make the best use of both, the whole must be controlled in as strict a regime as that exercised on its buses by the London Passenger Transport Board. It is to the means whereby we seek to achieve such an end—to the means whereby we seek to draw all these jumbled design threads together—the only means, in fact, short of nuclear power which will allow the nation to exercise the Constabulary Concept we have postulated, that we now turn.

We define this as the 'Upkeep Task' and it comprehends a very wide range of activity indeed; by the staff in the ships, by Fleet Maintenance staffs based either afloat or ashore which supplement the ship's own efforts and by the supply organization which provides spare parts and stores throughout the world.

Part of the task of the designer is to ensure that the machinery will maintain its performance with a minimum of skilled attention between the intervals when the ship as a whole has to be taken in hand for refit. On the other hand if he is to meet the stringent requirements of weight, space and efficiency, he must use the strength of materials to the utmost.

He is therefore called upon to advance in each new design to a region where the guarantee of absolute certainty is abandoned and a prudent limit is set only by his engineering experience and insight. Given time and money to test every component under realistic conditions he could then eliminate the inevitable failings to which every human creation is prone. But because of the rapidly changing requirements for ships and the financial scale to which naval machinery development has been confined, the necessary time and money has not in the past been given. Thus realistic conditions are almost impossible to reproduce except in actual service at sea. So it is that the upkeep task for each new design of machinery remains to a large extent a matter of conjecture until it is established by actual experience afloat.

For the sake of clarity the terms used in discussing the operational planning of ships' programmes are defined as follows. 'Availability' is that percentage of the total time between two stated dates when a ship is at the ready disposal of the 'Operational Commander'. Within that period there is also another period, 'Usage', when the ship is actually under way at sea or ordered to be ready to put to sea immediately. 'Reliability' is the ability to steam without component failures or loss of performance between the planned dates laid down for maintenance.

Experience has shown that it is one of the principal tasks of the staff at Headquarters responsible for the development and production of the equipment for the Fleet to achieve reliability in their equipment for the maximum periods before planned maintenance is necessary. If this is not achieved then technical officers and ratings at sea are ground to dust between the upper millstone of the operational task and the nether millstone of material unreliability, and their life becomes intolerable. If their lives do become intolerable they will leave the Royal Navy when their first period of service is ended; recruiting will suffer; standards will drop; and the whole maintenance effort will be in danger of collapse.

The burden of unreliability can also greatly be influenced by the standard of workmanship and finish at the periodical refits in a dockyard. Thus any study of the maintenance pattern must try to account for all these influences.

So we have a double task: to establish the facts of 'upkeep' in the Fleet and to postulate for the Fleet a programme of planned maintenance work which will keep it at its maximum availability. This experience must then be used to try to design our new ships with a well-contrived and practical schedule of maintenance work in mind and to share the work to the best advantage between short-term maintenance periods and the longer interval refits.

In this process of discovering where we are, we have established, after a fairly precise analysis, that there are some 4,000,000 man-hours of skilled and semi-skilled uniformed labour available to us each year at sea in ships or in what are called Fleet Maintenance Units, whereby we may keep the main propulsion machinery and the weapon and hotel services in fighting trim. We know also that if the ships are continually at sea this labour cannot be deployed and the programmed work and the unprogrammed work (defects) will build up and gradually accelerate until the ship has to be taken out of service for a prolonged period.

Our aim therefore must be to strike a bargain with the operational commander so that the ships are operated to a pattern which will give him the maximum possible overall availability. During the operational periods the build-up of programmed and unprogrammed work must not exceed that which can be brought back to a satisfactory level within the time allowed in the pattern for maintenance by the ship's company alone or assisted if necessary by a Fleet Maintenance Unit. In this equation there is always the most important single factor, the man himself. Unless he is maintained, unless periods are allowed for his rest and recreation after or during the material maintenance periods, then very quickly the ship will become quite unserviceable.

Enough of philosophy and let us turn to what we have actually done.

The vision of the senior officer who first walked round the Manadon Estate 27 years ago was that the College to be built here should encompass every sort of engineering skill which the Navy might need so that the consequent give and take in the different branches of engineering represented here would reflect in an all-round improvement everywhere. So it is that we who look after the machinery of the Fleet have borrowed much from those who deal with naval aircraft engines and there is now established at Portsmouth what is called the Ship Maintenance Authority.

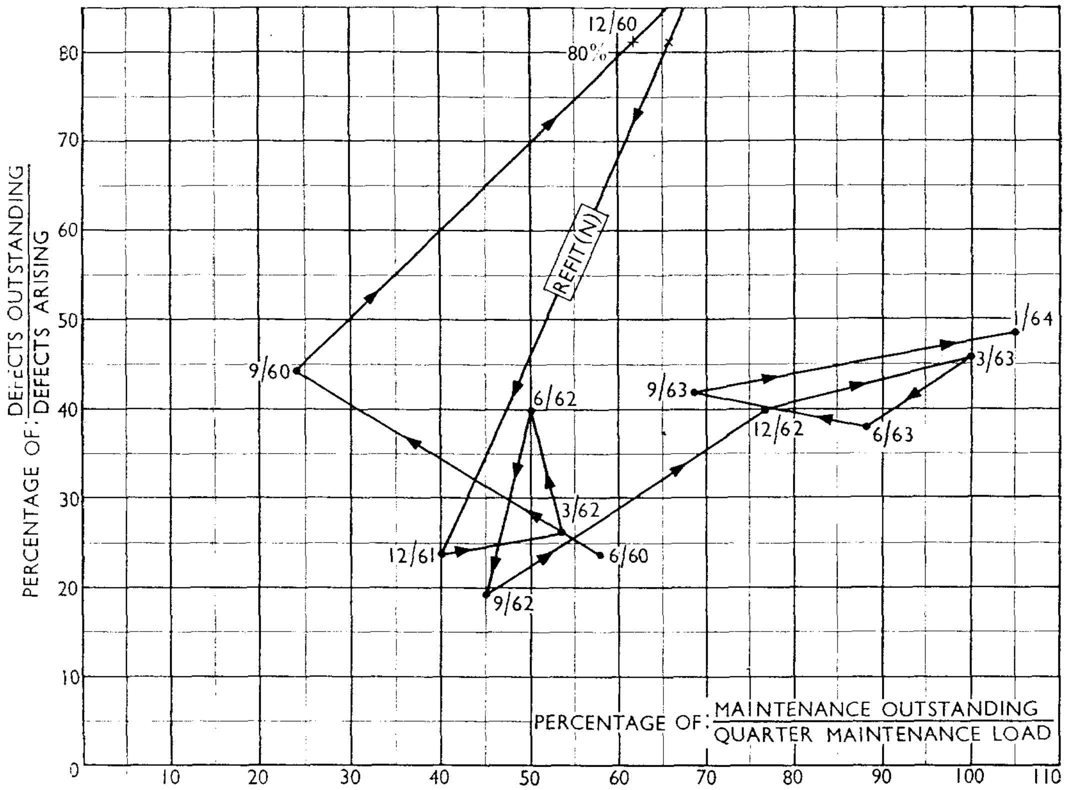

FIG. 1—AIRCRAFT CARRIER 'B'

This is a fact collecting body directly connected with the Director of Fleet Maintenance under the Director-General of Dockyards and Maintenance and also working closely with the Design Departments.

In the marine engineering field the Authority has established a number of what are called 'desks' and each of these 'desks' collates, records and analyses all the different reports from the Fleet and a few from the dockyards, too, concerning the particular equipment or equipments with which that 'desk' is concerned. This is gradually enabling two things to happen. Firstly, programmed upkeep by the Fleet, 'Planned Maintenance Schedules' as they are called, of the different equipments, is being reduced to the minimum consistent with the trouble-free performance of the equipment in question, thus deploying the minimum of manpower most effectively. Secondly, those equipments which are apparently basically unreliable, the ones which no amount of planned maintenance will keep trouble free, are gradually being identified and it is towards these that our very limited design modification effort and that of the manufacturers must be deployed.

Furthermore, there is building up in this way a body of experience which we hope will enable the designer to understand the factors which govern the need for maintenance and so reduce the task of maintenance. In the future we hope the operational commanders will be able to count on more precise standards of availability and usage, thus enhancing operational planning. In this connection we are beginning to assess what we might call the 'Far East Factor'. Something which, in time, affects not only the period taken to do a maintenance job, but also the precision with which it is done. Let us show you a few of the fruits of the Authority's labour.

The two graphs shown in Figs. 1 and 2 are of two aircraft carriers. Carrier B, an older ship, was on the old system of planned maintenance and Carrier A, a newer ship, is one in which, for various reasons, a more up to date method of planned maintenance has been applied.

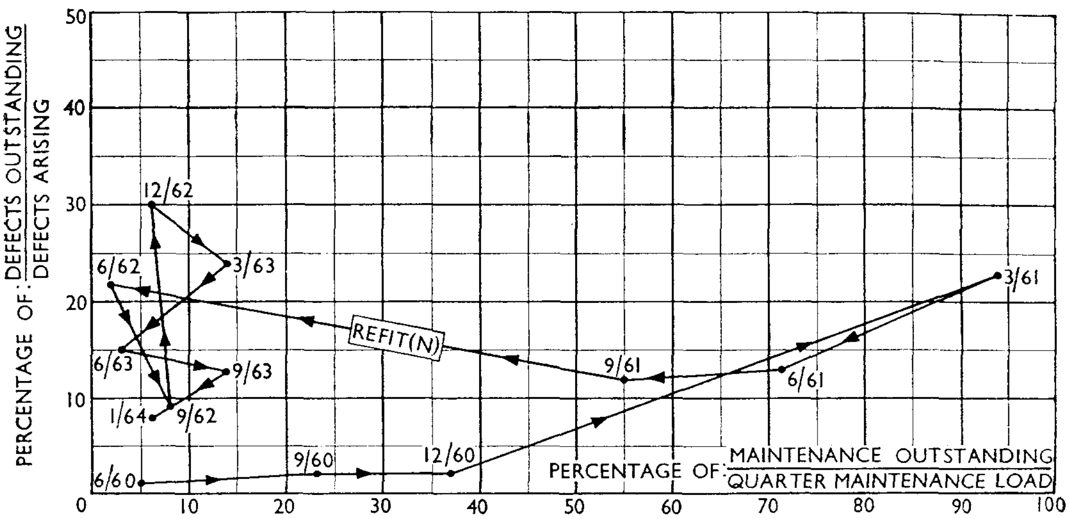

FIG. 2—AIRCRAFT CARRIER 'A'

We have on both pictures vertical ordinates giving as a percentage the proportion of defects outstanding to the defects arising at the end of a given period; these are the 'effect'. While on the horizontal ordinates, again as a percentage, we have the proportion of planned maintenance items outstanding over the maintenance load for a quarter. These are the 'Cause'.

First let us take the broad picture of Carrier B (FIG. 1) starting in the middle of 1960. From June till December, 1960 they plugged away at their planned maintenance while they were running, but in the quarter before their refit was due, both defects and planned maintenance started to get the better of them. Defects always mount up before a refit and in any case the ship was run very hard at this time. Then we see nearly a year of dockyard refit and with hindsight, for these statistics were not then kept, it seems probable that this refit was not long enough; 20 per cent of defects and 40 per cent of the planned maintenance items due for that period were outstanding only two months after the refit.

Now we come to a symptom which shows we were still only adolescent at that stage. It had not been fully appreciated at that time, and the control of planned maintenance on board ship was not sufficiently good to show it up, that the repair of major and minor defects often provides a golden opportunity to carry out an associated planned maintenance item for next to no cost in man-hours—opportunity maintenance. Neither was it mandatory for ships to carry out their correct proportion of planned maintenance items in each quarter and thus allow an even work load over the year.

So we see that in the fourth quarter they discovered a vast number of items outstanding and the whole plot shifted noticeably towards the breakdown point. In 1963 this bad situation was hardly contained and it is clear that the ship was losing the battle; and indeed, she arrived back in the U.K. in a poor state of upkeep.

Now let us look at Carrier A (FIG. 2), a newer ship it is true but one which we hope has been caught early enough to cope fully with the upkeep.

She started well but, again, before proper control and the new technical management were brought in, things started to go down-hill. Control was established and though seemingly after the refit there were more defects than before, they were all minor ones and the ship's staff and the Fleet Support brought them under control. There to all intents and purposes it has remained ever since. A very marked contrast exists between these two carriers.

To sum up, though there are setbacks we are very hopeful. There is no doubt that the Fleet is being operated at a pace unsurpassed before in peace, and probably war; and in general we are managing to do this while retaining a satisfactory degree of maintenance 'fat' in the ships. It is an unending struggle carried on not only in our own Material departments but in the fields of recruiting, training, welfare and by that faithful ally of us all, the senior psychologist. Unforeseen breakdowns still occur and can upset the whole maintenance pattern to which a prudent but hard pressed operational commander has acceded. When this happens at times of operational stress (and today this is the normal state) then a chain reaction of hastily done maintenance routines can occur, and if this is repeated a few times the maintenance fat is run off, planned maintenance items and defects outstanding begin to rise and many thousands of man-hours' work are needed to restore the situation. The analysis of experience which is now possible in the Ship Maintenance Authority is enabling us to lay down a pattern for the operation of each class of ship to give the optimum service. This we hope will give the operational commander the maximum use of ships and at the same time preserve the material in an efficient state.

CONCLUSIONS

We reach no very precise conclusions.

Lord Fisher, of course, was a law unto himself, and was able to be so because the Admiralty was small and so was the Government machine controlling it, in contrast to conditions today. Now, the issues are vastly more complex, technology more technical, and change faster. The structure for supervision and decision is also necessarily larger and more highly organized. No longer can one man be a law unto himself; instead, the organization must be made to work.

As far as conventional and nuclear propulsion machinery is concerned the total technical manpower at Headquarters responsible for design and monitoring design amounts to only about 65 professional and 200 draughtsmen grades, and of these nearly half are employed on 'post design' work in connection with the Running Fleet. The more the Fleet is used the greater the pressure on this attenuated staff and the greater the temptation to reinforce it at the expense of new and future machinery designs. We therefore have to call upon the best British Industry can produce to solve many of our problems and in this enterprise we have continually to be on our guard that no shadow of the 'not invented here' complex emerges to cloud our thinking.

We have learnt the hard way that however fine the design concept may be unscheduled breakdown, and the resulting inability to operate the ship, renders all our work sterile. In the past the early ships of each new class have tended to suffer in this way. In the future however high the cost (by naval standards) more attention must be paid to development testing.

Surveying the maritime scene over the last sixty years it seems to us that only at the beginning of that period and now, at the end, has any clear strategic pattern emerged from which a corresponding machinery design can be evolved. For the intervening period designs have tended to follow one another in a dull and rather unimaginative string within the terms of treaty limitations and along stereotyped concepts of battleships, cruisers, destroyers, submarines and, later, aircraft carriers.

The role of the Services today is gradually clearing from the mists which have enshrouded it in the last decade and it can now be defined as:

'the containment of violence throughout the world by the ordered application of force.'

Within this role the Royal Navy has to ensure the ready provision of sea/air power wherever it is called for and, in the circumstances likely to prevail for the foreseeable future this sea/air power will need to be deployed principally in the Singapore, Perth, Capetown, Aden, quadrilateral.

So this role and this environment are the two strategic facts which today must be kept in mind when designing the propulsion plants for the Fleet for the next decade.

To fulfil such a role in that, climatically, perhaps the most trying area in the world (and one moreover where vast sea distances are involved) means that we not only have to provide machinery which will give exceptional performance but also machinery with the ability to make life on board tolerable for long periods at sea.

Ships must therefore be able to go great distances for a minimum expenditure of fuel and they must have a quick 'reaction time' and be able to go at high speed. In addition a certain standard of comfort must be designed not only, as now, into the mess decks but also into the machinery and equipment spaces so that servicing is not a physically unendurable task.

Machinery must be designed for the minimum manpower not only for operating it but also for maintaining it.

Lastly, machinery must be designed and tested to a degree of reliability that will give the operational commander the absolute certainty, even in the most difficult strategic environment, that he can always count on it for trouble-free performance between well-defined maintenance periods. Furthermore, if these periods have been adhered to then he should also be able to count on trouble-free performance when an emergency occurs and operations become prolonged.

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15. Johnson, *Defence by Committee.*