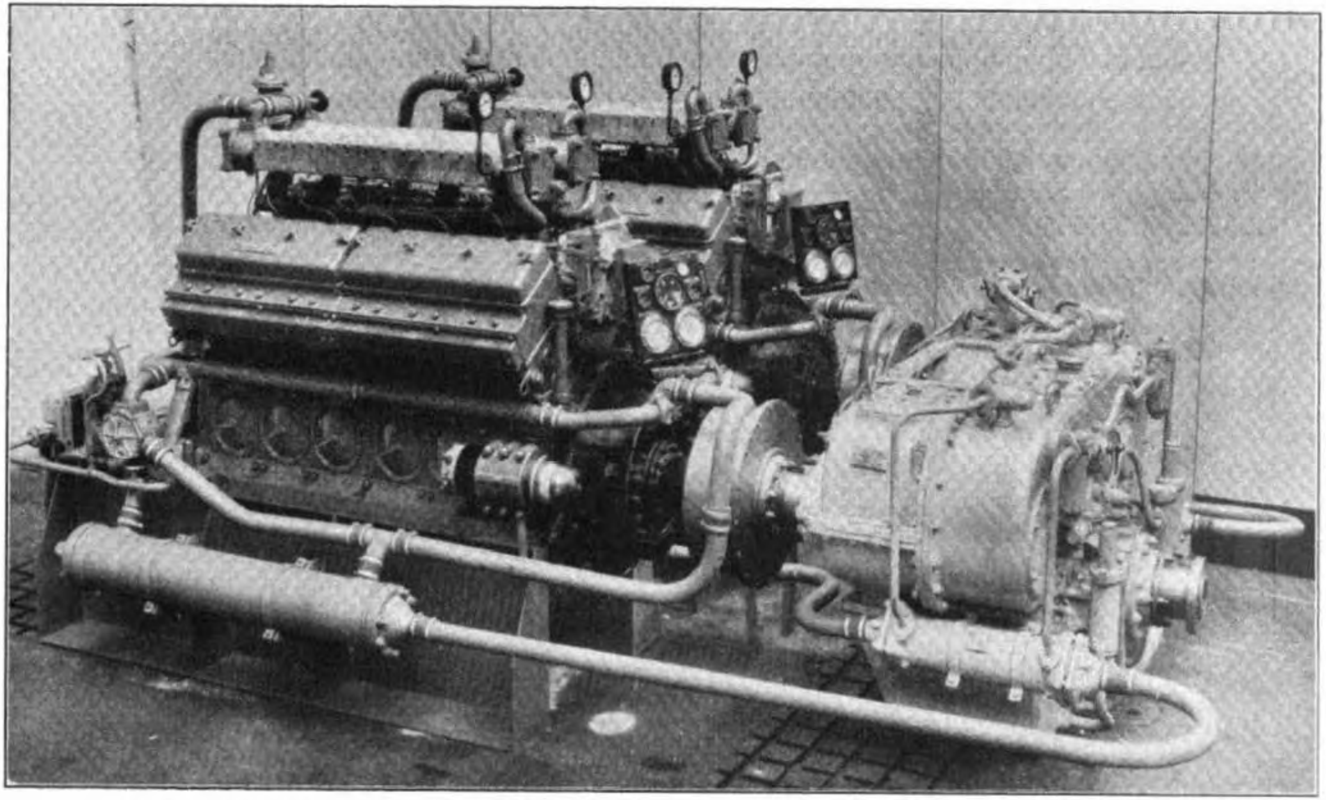


A Pair of Paxman, 12 T.P. Engines geared to a single shaft through oil-operated reverse gears for L.C.T. (8).

MARINE ENGINEERING FROM THE NAVAL ASPECT

by

ENGINEER VICE-ADMIRAL SIR JOHN KINGCOME, K.C.B.

This paper was read by the Engineer-in-Chief of the Fleet at one of the Controller's periodical inter-departmental discussions at the Admiralty on the 18th June, 1946. The audience was representative of all Departments. Owing to the necessity of adhering to the security grading of this periodical it is regretted that several points of special interest have had to be omitted from this reproduction.

In reviewing the subject of marine engineering as it affects the Navy it will be my aim to deal only with broad principles as they affect us all and to sketch in outline the important features which bring out the character of the problem.

My method of dealing with the subject will be to take in turn the various sections into which it can be divided. For each I shall touch on the advances made between the wars both by ourselves and by several foreign powers. This will lead in each section to a brief review of the present position, and, turning to the future, which is now the major concern of us all, to an outline of our policy. In covering the ground I shall endeavour to bring home the difficulties inseparable from rapid advance in the high power marine engineering field and to contrast the facilities available to us and to our rivals.

Before starting, and in order to give a background to my theme, I shall just outline the form which I think propulsion machinery will take in the near future. In doing so I omit all reference to atomic energy, since I do not think it will be a real factor in warship propulsion for, say, the next ten years.

Surface vessels

In my view the most suitable propulsion machinery for surface vessels in the immediate years ahead will be :—

1. *Diesel Engines* for low powers, say, up to 2,000-3,000 H.P. per set. These could, in suitable cases, be grouped round one set of gearing to give up to four times this power per shaft. An example of this is in the L.C.T. 8, where two 500 H.P. engines are connected to each shaft. Diesel machinery has the advantages of low fuel consumption and instant readiness ; moreover, it lends itself readily to mass production in a field of industry not normally tapped to any great extent for marine work. Maintenance is, however, a major problem, but this can be simplified, where small units are used, by changing engines on board, and by overhauling the used engines in properly equipped establishments ashore.

2. *Gas Turbines* for intermediate powers.

   As far as we can see at present the gas turbine is not likely to be suitable for the lowest powers, say, below 2,000 H.P., nor can we say at present whether it will have an upper limit, but 10,000-12,000 H.P. sets may be available in, say, ten years' time. Gas turbines also have the advantages of low fuel consumption and instant readiness, but we do not yet know what difficulties will be met with in their operation and we are therefore particularly anxious to instal one of these units in a seagoing ship as soon as possible in order to gain this experience.

In order to extend the use of gas turbines into higher powered fields, it may be possible to group a number of sets round one gearing in the manner referred to above for Diesels.

3. *Steam Turbine machinery* for high powers.

An interesting possibility of the future is a combination of steam machinery with gas turbines for boost power, e.g., to meet the staff requirement of quicker acceleration for aircraft carriers.

Submarines

In order to meet staff requirements for high underwater speeds for submarines the high power required will necessitate the use of turbine machinery and it will also be essential that the oxygen required for combustion is carried in some form or other or produced on board. The only method developed at present uses hydrogen peroxide, which provides superheated steam and the oxygen necessary to burn the fuel for which stowage also has to be provided. The propulsion machinery for such a submarine would consist of a Diesel engine for surface propulsion and to give high endurance under " snort " conditions, electric propulsion from batteries for totally submerged work, with the turbine machinery for bursts of high underwater speed.

With the quickening of interest in research in the marine engineering field, it is evident that big developments are likely to occur in the next few years, and it is essential that the Admiralty should take the lead in these developments. In order to assist me in my task, the Board have approved the setting up of the Marine Propulsion Committee with wide terms of reference covering the improving of existing forms of propulsion and the development of new ones.

Steam Power Plant

I shall now deal with the various types of machinery in turn, and I propose to start with steam, as this is likely to be used in all our major ships for some years to come. Here the basic factors available for variation are the pressure and temperature of the steam generated by the boilers. Raising the pressure and temperature increases the thermodynamic potential and, if advantage can be taken of it, the overall efficiency of the installation.

At the end of the 1914-18 war our ships used saturated steam generally at about 220 lb./sq. in. the temperature being about 400°F. The use of superheated steam was adopted as policy for the postwar fleet commencing with H.M.S. *Amazon* and H.M.S. *Ambuscade* and the *County* Class cruisers, and by the outbreak of the recent war the steam conditions of larger ships had advanced to 400 lb./sq. in. superheated to 700°F. For destroyers it had been held at 300 lb./sq. in./650°F. for production and maintenance reasons. We had also carried out trials with a 500 lb. 700°F. unit in H.M.S. *Acheron*, but just when we were prepared for another step forward financial stringency and the unsettled state of world affairs prevented further action.

The cumulative effect of the advances in the twenty odd years is well illustrated by the re-engining of *Queen Elizabeth* Class, mentioned by Sir Stanley Goodall in his recent paper to the Institute of Naval Architects. In this reconstruction, the original twenty-four boilers supplying saturated steam to direct drive turbines were replaced by eight boilers supplying superheated steam to geared turbines, and as a result the space occupied by the machinery was reduced by one-third, the machinery weight was halved and the endurance at ten knots was trebled. This not inconsiderable achievement was largely produced by a slow and laborious step-by-step method, in which every new advance could only be tried out in the next year's programme.

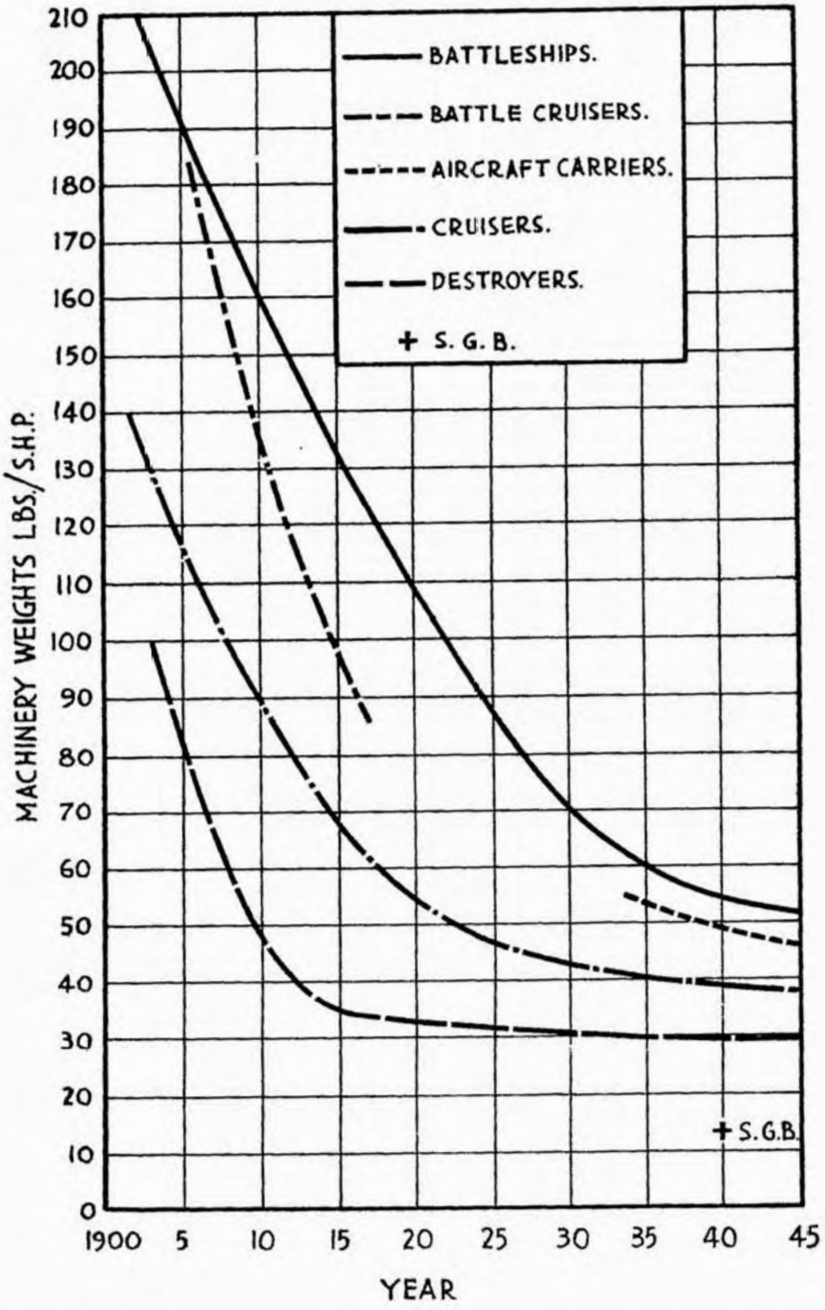
It is not out of place here to mention the great difference that exists between development in the long life engineering field and that in the field of lighter engineering. In the latter, the building and thorough testing of prototype designs is a comparatively quick and inexpensive matter and it is, therefore, customary for this to be done before the final programme is decided on. The case of the motor car is a simple example. Where only short life is looked for from the engine, this method is even more attractive. In the aero world, for instance, where jet engines have a maximum life of 300 to 500 hours, tests measured in days or weeks suffice. In the marine field where a life measured in tens of thousands of hours is concerned, it is a very different matter. Quite apart from this, the size and expense of making prototype designs puts another complexion on the problem.

Lack of facilities for the full scale testing ashore of the machinery of ships is undoubtedly a considerable handicap to rapid development, since failures, once machinery has been installed, must be avoided at all costs. America recognised this need and provided the necessary plant for the U.S. Navy at the Boiler and Turbine Laboratory, Philadelphia. The Germans went to even greater lengths and provided the majority of their warship engine builders with two sets of equipment so that every set of steam machinery for their warships could be tested at full power ashore before being placed on board. During the '30's, the U.S. Navy, who had been keenly interested in our *Acheron* trials, decided to go for higher pressures and temperatures and after considerable research and testing, had, by 1939, standardised at 600 lb. and 850°F. for their whole fleet.

At temperatures exceeding 750°F. we enter the range where " creep " becomes the major design factor. Perhaps I should mention that creep is the name given to the tendency of metals to become plastic under stress at high temperatures. This calls for a much higher standard of technical design, the use of special materials and, of very great importance, greater precision from industry. The U.S. Navy expected and experienced a good deal of initial trouble, firstly in educating industry to meet the special needs of naval machinery for higher steam conditions, and later with the material itself on service. The gains in fuel consumption which can be expected in practice from increased steam conditions, assuming that full advantage can be taken in the auxiliary machinery as well as the main turbines—this is the difficult point—have been well established by experience in power stations. They amount to about 5 per cent. per 100°F., at 700°F. falling to about 3 per cent. at 900°F. Increase in steam pressure is a less easy subject on which to generalise except to say that there is an ideal pressure for each application and that the gain is just over 1 per cent. per 100 lb. pressure rise in the zone 400-600 lb./sq. in. The direct saving in fuel due to the use of the higher steam conditions in American ships as compared with ours is therefore about 8 per cent.

In the case of the Germans the *Narvik* Class destroyers had machinery designed for steam conditions of 1,100 lb./sq. in. 930°F. during bursts at overload power. It was, however, normally operated at lower conditions. The Germans used this high pressure in an endeavour to reduce steam pipe sizes and so get the machinery into a smaller space. The result was undoubtedly a failure. They got an extremely congested arrangement with a high degree of complication requiring nearly twice the number of engine-room personnel that we normally

MACHINERY WEIGHT CURVES



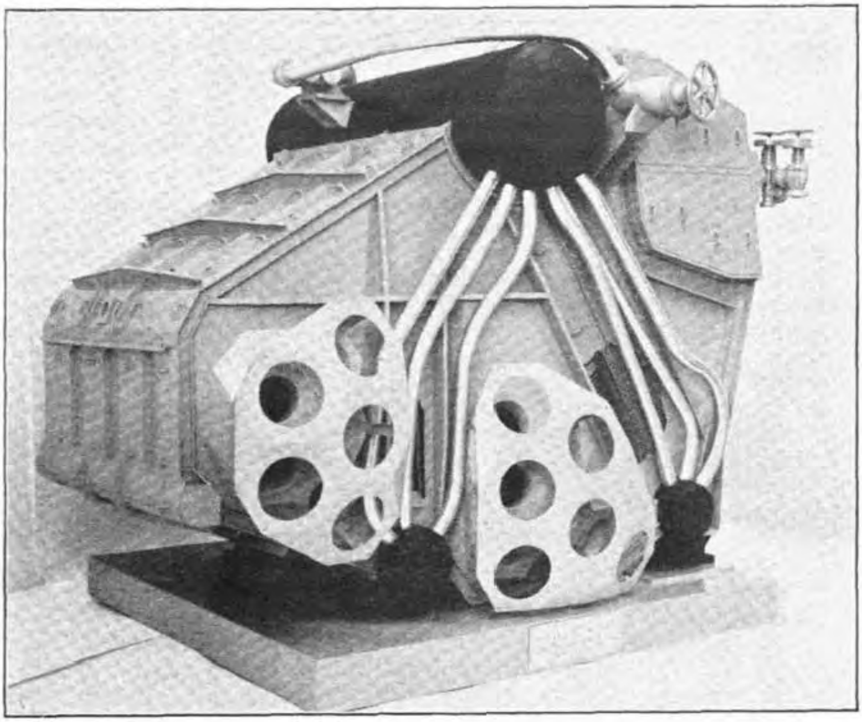
carry. The ships had doubtful reliability—and had a higher fuel consumption than that of our destroyers. The machinery of the 69,000 H.P. *Narviks* is 25 per cent. heavier than that of our 72,000 H.P. fast minelayers and it occupies roughly the same space. Although the design was extremely ingenious and indeed contains a number of features which we are following up, the machinery as a whole has, I think, been aptly described as a masterpiece of misapplication.

The highest conditions which can as yet be regarded as normal in power station practice are 1,250 lb./sq. in. 950°F., though some stations use 2,000 lb./sq. in. I might mention in passing that steam pipe failures are somewhat alarmingly prevalent just now in power station work. It has often been asked why similar practice cannot be directly applied to warships. There is a fundamental difference between the two requirements. Unlike naval turbines, power plant turbines operate at one speed only and are seldom called upon to change power very rapidly and without notice. In addition many of the small auxiliary steam machines which go into a warship must run efficiently with the steam conditions produced by the main boilers. In power stations the latter problem is met by the use of electric motor drive ; weight, space and risk of flooding not having to be taken into consideration. I must also mention, and it is not without significance, that the latest trend in power station practice is to redesign new stations for 900 lb./sq. in./900°F.

The present position as far as the Royal Navy is concerned is that we are adopting steam conditions of 650 lb./sq. in. and 850°F. for the machinery of the *Daring* Class destroyers, which is sensibly the same as the U.S.N. standard condition, but higher than anything yet handled by the marine engineering industry in this country. Great advances are required in the technique of turbine detail design and manufacture, in the production of high precision gearing, in steam valve and steam pipe manufacture and in many other directions, and it has been no easy matter to educate the marine engineering firms up to the standards now required; even on the inspection side we have had to give guidance and assistance. One encouraging sign is that all the firms are now interested and keen to build this machinery, and so gain experience. It is quite probable that we shall have considerable teething troubles with the machinery of these ships, but these will be overcome and high pressure and temperature will become the standard in the future.

We do not, however, intend to stop at the present figures, but to proceed to higher pressures and temperatures as swiftly, rationally and economically as is practicable. I have referred to the German policy which led to what can be termed a major engineering failure. We know the Americans are experimenting with the use of steam conditions very similar to those adopted by the Germans. We hope to avoid mistakes and to produce for our ships only that steam machinery which is best fitted to meet the peculiar and onerous demands of warships. We have, therefore, to determine those steam pressures which are as ideal as possible to suit all aspects—reliability, efficiency, weight and space, and economy of manpower. To do this, approval has been sought to place a contract for the whole field to be examined jointly by Messrs. Yarrow, Ltd., and the English Electric Company, after which their recommendations will be submitted to the Marine Propulsion Committee. This research will be of considerable scope, incidentally involving almost complete designs of several machinery layouts and examination of what is required by industry to meet them in each field, boilers, turbines, auxiliary machinery, etc.

Having established the most suitable steam conditions for warships, we will then have to find the means of producing designs and prototypes to use these conditions. The main items are boilers, propulsion turbines, double reduction gearing and auxiliary engines, with each of which I shall now deal in a little more detail.



Model of Foster Wheeler Controlled Superheat Naval Boiler

Boilers

Backed by the experimental and development work carried out by the Admiralty Fuel Experimental Station at Haslar, considerable strides were made in oil fuel burning and boiler design between the wars. As an example, the 42 boilers originally fitted in H.M.S. *Renown* were, at her reconstruction, replaced by 8 Admiralty design 3 drum boilers capable of producing the steam required for 120,000 S.H.P.

The rate of advance was, however, limited by the inadequacy of the facilities at Haslar and we had to adopt the policy of using a ship's boiler for full scale trials ashore. The first of these was on a boiler for H.M.S. *Rodney*, and later on boilers for *County* Class and an " I " Class destroyer ; these gave us very useful data but the period between trials was too long, and we nearly ran into trouble with the fast minelayer boiler design. We have now built a boiler test shop at Clydebank and carry out full scale trials of all new design boilers before installation. It is hoped to build a new Haslar on the Tyne in the near future where all future research and development on boilers and fuel burning arrangements can be concentrated in one establishment.

Admiralty boilers are natural circulation boilers, and there has been a good deal of pressure from certain quarters to use forced circulation boilers. We did, in fact, fit one of these boilers (a La Mont) in an " I " Class destroyer and also during the war in half the steam gunboats, but our experience has not shown them to be any more suitable for naval purposes than our own design. The Germans also investigated this problem, and fitted a number of forced circulation boilers of the La Mont and Benson type but reverted to the natural circulation Wagner boiler in their latest ships. These designs have been thoroughly investigated by Admiralty and Industry and in general they show no advantages over our own, indeed, they have all given very considerable trouble. To assist our own development, however, we intend to carry out trials at Messrs. Thornycroft's on the latest design of German Benson boiler.

The Americans stuck to the natural circulation boiler, but introduced controlled superheat which permits of the maintenance of high temperature down to low shaft powers and thus an improvement in economy at these powers, as well as enabling astern turbines to operate at reduced temperature and permit prolonged astern running without overheating. We ourselves have already introduced this type of boiler in *Weapons* Class destroyers.

In the *Daring* Class three different designs of boilers will be used—Babcock, which is a complete U.S. design, and Foster Wheeler and Yarrow, both British designs. Boiler developments to use the new higher steam conditions will naturally depend on experience with all these new designs.

The French Navy, in an effort to reduce space, has developed a boiler in which combustion takes place at about twice atmospheric pressure. Several boilers of this type were fitted in *Richelieu* and one or two other ships. The Germans also investigated project designs of this nature. Fundamental data on this problem are lacking. The possibilities of a higher rate of heat transfer with a reduction in combustion volume leading to reductions in overall weight and space make it imperative to institute the necessary research. We intend to do this, but no work has been done on the subject in this country and much development will be required. It is also likely that we shall adopt the closed boiler with open stokeholds which gives promise of better habitability, apart from giving wider scope for development. We shall then ask D.N.C. to ventilate the stokehold.

We have already taken automatic control of the feed water further than the U.S. Navy and some greater measure of automatic control of the boiler equipment is likely to be desirable. This is under investigation. I must, however, point out that automatic control will not reduce the number of personnel required. Witness the *Narvik* Class, which I have already mentioned, which, although fully automatic, required an engine-room complement just twice that of our fast minelayers.

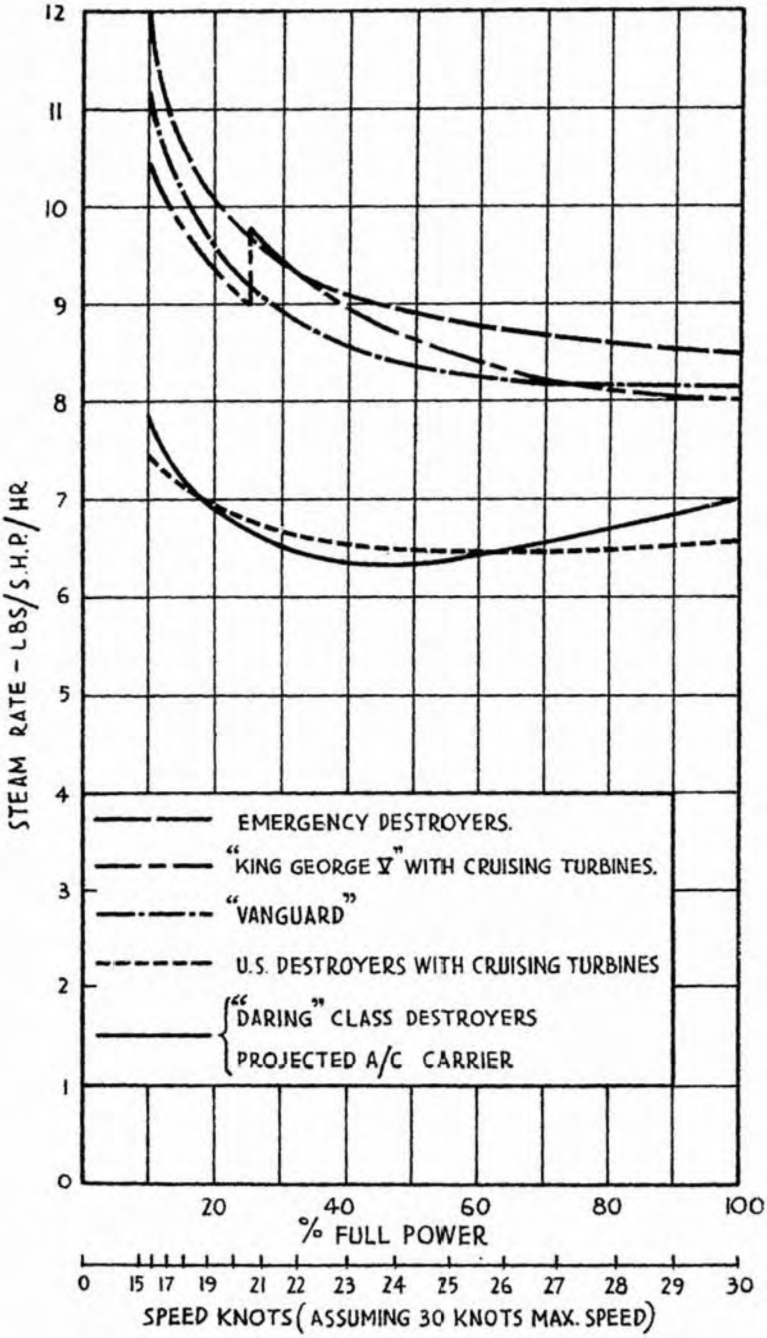
Propulsion Turbines

At the end of the 1914-18 war the comparatively low steam conditions allowed the use of large slow-running turbines which drove the propeller shaft direct, though gearing would have been an advantage. The advance in steam conditions, which I have mentioned, called for a corresponding increase in the rotational speed of the turbines and the use of reduction gearing between turbine and propeller shaft became necessary.

When the use of higher steam conditions was decided on, it was evident that we should need extensive research facilities, and it was proposed to set up an Admiralty steam turbine research establishment. This was discussed with the late Sir Charles Craven, who, after consulting the marine engineering firms, put up the alternative proposal that the industry should set up their own research station. In these circumstances the Admiralty proposal was dropped and P.A.M.E.T.R.A.D.A. was born. This Association has the backing of the Admiralty and the buildings are now well under way.

The site at Newcastle will be equipped by the autumn of this year for the full scale testing of steam turbine plant up to 60,000 S.H.P. per shaft. Guided

STEAM RATE CURVES



by my Turbine Design Section, and by Messrs. C. A. Parsons and The British Thomson-Houston Company, the Association is handling two of the three turbine designs being fitted in *Daring* Class.

In addition, two of these ships building by Messrs. Yarrow will have English Electric Company-Yarrow turbines, which it is hoped will embody all the lessons so far learnt in land turbine design at these steam conditions. The Association will later on test all three prototypes ashore under full load conditions. In these three designs, we are obtaining the benefit of the experience of three of the major land turbine firms, and the spirit of competition, so essential for advance, will thus be infused into the marine industry and it is hoped that nothing but good will come of it.

Staff Requirements

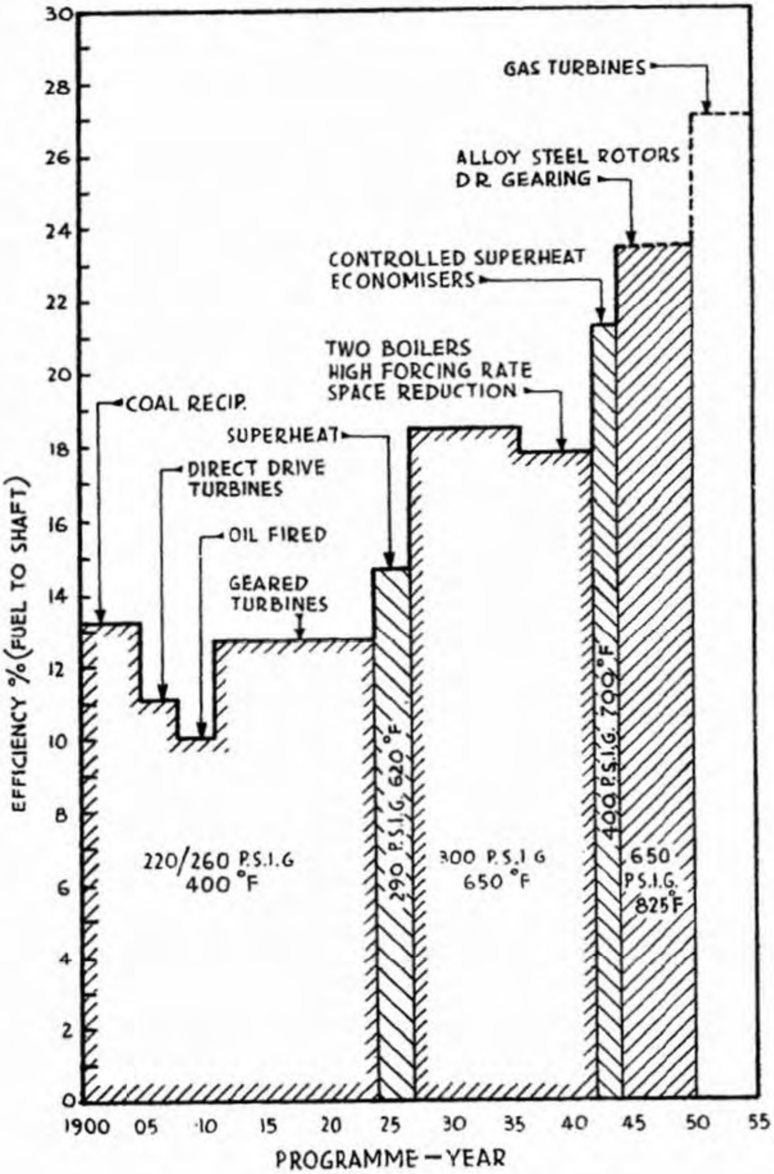
At this point I propose to digress from my theme for a few moments. The endurance at war cruising speeds depends greatly on the design of the main turbines. The U.S. Navy deliberately sacrificed economy at full speed to achieve greater endurance at war cruising speeds. This was clearly demonstrated by a comparison of the performance of the *King George V* with that of the U.S.S. *Washington*, which at 20 knots was much more efficient than the British ship.

I want to stress this point : not more than a quarter of this gain was due to higher steam conditions, a third was due to the use of the economisers and controlled superheat, and the remainder was due to the turbines being designed for this speed. At full speed, however, the *Washington* had a lower figure for miles per ton of fuel than the *King George V*, which had been designed for maximum cruising at full power. We have taken the step in the *Daring* Class to improve the endurance at war cruising speeds and the effect of the change in design is shown by the curves on Page 8. It will be readily realised that the correct framing of staff requirements to achieve the best compromise calls for a very clear appreciation of the factors involved.

Auxiliary Machinery

While on the subject of turbines I should like to say a word about auxiliary machinery. The saturated steam in use at the end of the 1914-18 war permitted the use of reciprocating auxiliaries which though somewhat heavy, were economical in the use of steam. The adoption of superheat brought with it the use of turbine driven auxiliaries and rotary pumps. These are compact and light but have a steam consumption heavy enough to have an important effect on the economy of the ship as a whole. This is especially important as steam pressures and temperatures rise because unless the efficiency of the auxiliaries keeps pace with that of the main engines, the theoretical overall gains cannot be realised. Unfortunately, as steam pressures and temperatures rise, so at an increasing rate does the intricacy of the design of small turbines. We are, therefore, placing considerable emphasis on this important requirement, which neither the U.S. nor the German Navies have yet solved satisfactorily. I am sure you will be pleased to know that even our American friends own that we are ahead of them with our steam auxiliary machinery. We hope to maintain this lead and to assist us the leading German turbine designer and the leading German gearing designer in this field, both of whom have world-wide reputations and neither of whom appear to have been used efficiently by the Germany Navy, are being brought to this country as consultants to our auxiliary machinery firms, with whom contracts for the development of advanced auxiliary engines will be placed.

FULL POWER EFFICIENCY DIAGRAM



Reduction Gearing

There is little doubt that the use of reduction gearing will grow in every field of engineering. In the propulsion field, British gearing led the field for many years, the standard gearing being of the single reduction type. Double reduction gearing was developed commercially towards the end of the 1914-18 war, but there were so many failures that it fell into disfavour. In America the adoption of high pressure temperature steam conditions would have been hindered by the use of single reduction gearing, so by devoting great energy to the problem they overcame the difficulties, and produced a satisfactory double reduction gear.

We have adopted a similar double reduction gearing in our *Daring* Class. The designs have been worked out by P.A.M.E.T.R.A.D.A. in conjunction with my Gearing Design Section, a new tooth form has been designed for it and a much higher standard of accuracy has been demanded of the hobbing machines than hitherto required in this country. In addition, the post hobbing processes of shaving and lapping are to be used.

To get early experience on a small scale, we fitted this kind of gearing in two *Loch* Class frigates. These successful gears, designed and made by The British Thomson-Houston Company, were the first locked train double reduction gears designed and produced in this country for the Navy.

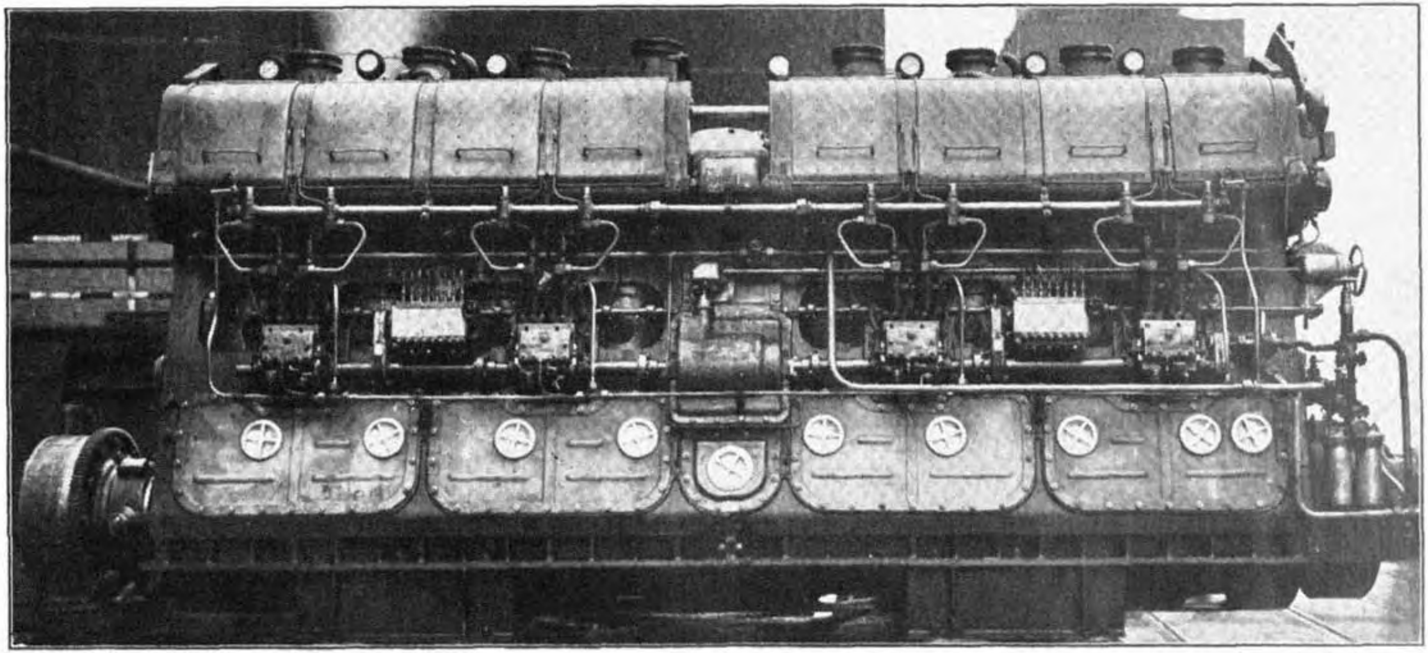
Following the use of hardened and ground gears in automobile and aero gears, developments have been under way in Switzerland at the works of Messrs. Maag, Zurich, for many years directed to using similar processes for high power transmission gears. These appear to be so promising that we hope to obtain early experience by fitting such gears designed and built in Switzerland in one of the *Daring* Class. These gears will be 30 per cent. lighter than the present design and will also save space.

Missions to the U.S.A. and Switzerland have led to a realisation of the position by our own industry. Sponsored by the Admiralty, the British Standards Institution have set up a committee under the chairmanship of Assistant E.-in-C. (Research and Development) to lay down improved standards for gear hobbing machines and a research partnership including Messrs. Vickers and Messrs. David Brown and Messrs. Craven's and Messrs. Muir's, the leading hobbing machine makers, has been formed to carry out research and development into advanced gear production for the Admiralty. This is a union, on the research side only, of machine tool makers with large and small gear manufacturers, to bring gear production up to the very high standards now required. Here again, the advice, encouragement and some finance have come from the Admiralty, and to keep the progress going will need a great technical effort on our part.

I.C. Engine Field

The design of submarine engines has been mainly carried out by my submarine section in collaboration with H.M. Dockyard, Chatham, the Admiralty Engineering Laboratory, West Drayton, and by Messrs. Vickers at Barrow. The engines in use in the 1914-18 war were mainly of Vickers design of direct injection type, and were criticised for being smoky. In the post-war years we developed engines of the blast injection type, but a good deal of piston trouble was experienced mainly due to distortion of the large diameter aluminium pistons then fitted. Subsequently, technical progress enabled us to revert to direct injection which has the advantage of simplicity, and we developed two new designs for the " S " Class then in production and for the new " T " Class.

As so often happens after a war, there was a good deal of critical comparison



Admiralty " S " Class submarine engine

of our engines with the German and the French and when " T " Class were started, it was decided to try out all four types, two British, two foreign. The 1938 crisis overtook the experimental aspect of this project, but all four types were by then in the production stage, and were, in fact, fitted. For the greatly increased building programme the rest of the class were fitted with Vickers and Admiralty " T " Class engines, which had proved themselves superior to the German M.A.N. and the French Sulzer.

In the " U " Class a radical machinery departure was made from the conventional direct drive to Diesel electric drive, using high speed engines, since this form of drive is peculiarly suitable for small submarines. I think I am not likely to be contradicted if I say that British Diesel engines for submarines have proved to be just as satisfactory as those of the German or U.S. navies. In the smaller types of Diesel engine, we have British makes like the Gardner, which are as good as the American designs, but it must be accepted that the Americans had a much wider range, and much greater production capacity than we had, mainly due to the greater use of this type of machinery in the U.S. commercial world.

German Diesel engine development was, however, in many respects ahead of that in Britain and the United States. E-boats were fitted with a 2,500 B.H.P. Mercedes Benz engine of light weight construction ; even so, they weigh 4 lb./B.H.P. This was a direct development of their Zeppelin engine and had no counterpart elsewhere. The Germans, possibly because of their troubles with steam machinery, had embarked on a policy of the development of large power Diesel engines suitable for installation in destroyers and battleships, and had in fact decided so to engine their post-war fleet, if and when they had beaten us in 1942. Three engines, each of 10,000 B.H.P. had been built and run at the M.A.N. works at Mannheim in the U.S. Zone of Germany. We have been successful in obtaining two of these engines in order to carry out extended tests at Chatham to investigate the maintenance problem.

So far as the future is concerned we consider that the general level which the design of the internal combustion engine has reached justifies a policy of standardisation. We have proposed to develop a series of standard engines which, together, will cover the whole power range of requirements from 5 to 2,000 B.H.P. This will involve the development of existing standard engines in some cases and new ones in others, exactly to meet the special needs of the Navy and to be capable of simple mass production. The scheme envisaged is for production of parts to standard jig which can, in emergency, be spread throughout industry. The assembly and test of engines to take place in special factories. The scheme has been approved in principle. Its benefits and implications are so far-reaching that an Inter-services Committee under the Chairmanship of an Assistant E.-in-C., is at present considering how the needs of all the Services can be met by the one scheme. It will be appreciated that here again much research and development will be needed to ensure that the standard designs are as perfect as possible. It is a commitment, of course, which must be planned and completed in peace-time. These standard engines are intended to cover all our needs from motor boats, generating plant ashore and afloat, to main propulsion.

In the light weight, high-speed special purpose Diesel engine field, there has long been a need for an engine of high power with very low weight for coastal force craft. This need was appreciated before the war, and we had a development contract with Ricardo-Paxman for a 1,000 H.P. light weight engine. Unfortunately, these engines were only about to reach the testing stage when the war broke out, and were never completed, as by this time the power required had risen above the 1,000 H.P. level. The effort was not wasted, as the design formed the basis of the Paxman engines fitted in our L.C.T.'s and in the Camper Nicholson boats, which did such good service in running the German blockade later in the war.

In 1943 the Fedden Committee was set up to examine the whole problem, and it has been approved to place a contract with the English Electric Company for the development of an engine of 2,500/3,000 H.P.

Gas Turbine Field

This is a relatively new field in which much pioneer work has been done in Switzerland during the war. Brown Boveri, who started work ten years ago, undoubtedly led the world in the actual production of working gas turbines, principally for power station stand-by plants and for locomotives. Sulzer's have been at work since 1939 and have, since 1941, been developing a plant for merchant ships which is due to run next March. Escher-Wyss are now working on a 6,000 S.H.P. marine design.

In America the Navy has, since 1941, been developing gas turbines in co-operation with many commercial firms. At the Naval Engineering Experimental Station, Annapolis, a large and heavy plant, unsuitable for marine purposes has been under test for two years. A second plant has been on test at the works of its designers, the Elliott Company, for a long time. As a result of the trials two new plants of 3 000 H.P. each are being designed and built for the U.S. Navy and the shop trials of the first plant will complete in January, 1947, the second two months later. These sets are to be installed in two Diesel electric drive destroyer escorts in place of one of the sets with Diesel machinery. The two ships will then run an extensive series of comparative trials, being looked upon as purely experimental and non-operational. The Maritime Commission are also ordering one or two similar plants from this Company for installation in merchant vessels. This illustrates the strides the Americans with their large resources can make when they decide to, and emphasises the determined effort necessary on our part.

The gas turbine for ship propulsion has the advantages of lower fuel consumption and more instant readiness than steam plant and its adoption may result in a reduction in space and probably also in weight of machinery. There are also some disadvantages, and there are many difficulties to be dealt with. Among them are the large deck openings to admit the air supply required, the provision of a source of power for auxiliary machinery and a solution to the astern problem. A radical alteration in funnel position to meet the different lay-out of machinery may also be involved. It is, however, quite certain that the benefits which can be offered by gas turbine machinery make determined and rapid development imperative.

There was no development of the gas turbine for marine purposes carried out before the war. The recent rapid strides made by the jet engine in this country spurred engineers in other fields to give more serious consideration to this type of plant, but very little practical advance could be made because the research and development effort was required elsewhere. Towards the end of the war, when effort became freer, no government facilities were available and all the industrial capacity had been bought up by the Ministry of Aircraft Production. It is as well to explain here that it is no easy step from a well developed short life aero jet engine to one for marine use. There are two major and fundamental differences between aero and marine engine requirements. One is the life of the engine and the other the power range over which the engine must be able to operate continually and economically. Aero jet engines, as already mentioned, have a life of 300 to 500 hours and need good efficiency only at or about full power. On the other hand, marine engines for propulsion purposes have in the past been designed to last the life of the ship reckoned at 100,000 hours in operation. It is likely that we shall have to alter radically our conception of engine life and perhaps face up to re-engining at intervals. But, in any case, the aero figure of 500 hours must be very greatly lengthened. Life, to a great extent determines the operating gas temperature and thus the efficiency obtainable. Aero engines are using gas temperatures up to 1,500°F., but it is unlikely that the longer life marine unit will be able to use more than 1,300°F. for some years to come. Even with this temperature the design of multi-stage turbines for the life and power required for marine propulsion is well outside any previous knowledge and experience. Possibly an even greater headache is the fact that a marine engine must be able to operate continuously at all powers between " full ahead " and " full astern " and must have high efficiency at cruising powers. This involves design problems which have shaken even the normally optimistic aero industry. In a nutshell, a very great deal of research and development is required, and it is bound to be very costly. As an example, in the aero field it is only necessary to run tests to determine the creep properties of all the various special materials used in construction for 300 hours or so. Nothing less than 10,000 hours' life is of real value for marine applications and even this may not be really sufficient. To determine a set of creep curves for one material, at two temperatures only, involves about a dozen tests each of 10,000 hours, that is, even these bare tests on one material occupy 12 machine years. I do not think it is any exaggeration to say that aero engine development is simple compared with our problem.

In this new field of advance we have thought it wise to divide our activities into two groups, medium life, for coastal craft, and long life for ships. In each group we have a short and a longer term policy. In the coastal craft field we shall obtain early experience from a converted aero engine design. This consists of a gas turbine arranged to cut in for high speed requirements to drive an M.T.B. which has normal engines on the wing shafts. The aero combustion unit has been modified to burn Diesel fuel, and a specially designed power turbine and gears take the place of the aero jet.

The machinery I have just outlined can only be regarded as a stopgap, because having poor efficiency at low powers it can only be used, in conjunction with existing economical machinery, to give bursts of high speed. As well as this, it will, however, give us early marine operating experience of gas turbines. This is very necessary as marine conditions always require more robust machinery and the salt-laden air is a new and as yet unsolved problem.

How best to cover the problem of long-term development it is the function of the Marine Propulsion Committee to advise. We are, however, putting our specific requirements to all interested firms with a view to designing and building at the earliest possible date a plant suitable for naval requirements with economy at low powers, and if possible, capable of development to higher powers so that we may not lag behind other countries in this most important field. At the same time as we develop the gas turbine we must consider the type of auxiliary machinery required, as well as the means of going astern. For auxiliaries it may be that A.C. electric power coupled with gas turbine driven generators will be the solution.

For reversing, various means are being discussed and a hydraulic method is likely to be on test next year at P.A.M.E.T.R.A.D.A. The variable pitch reversing propeller is one possible solution to this problem. Propellers of this type made by Messrs. Rotol are being tried out in M.T.B.'s and we also have a design in hand for a tug, but much development work will be required to produce the propellers for higher powers and larger ships.

Submarine Field

High submerged speeds for submarines have been a staff requirement for many years and the former Submarine Propulsion Committee considered it as one of their main targets. As already mentioned, the problem is the provision of oxygen to burn fuel in an engine which has the relatively high power necessary for the speed. Among the systems examined in pre-war days was the storage of liquid or gaseous oxygen to replace air in the Diesel engine, the production of oxygen by electrolysis of sea-water and the possible use of substances which carry oxygen. The Germans were also working on this problem and whilst they stuck to oxygen they do not appear to have been any more successful than we were. The Germans had, however, concentrated on alternative oxygen bearing liquids and had been successful in developing under the stimulus of Dr. Walter, a system of submarine propulsion using turbine machinery to give the high power necessary for very high under-water speed. The oxygen carrier they used is Hydrogen Peroxide (H.T.P.) which stands for High Test Peroxide. This can be decomposed into superheated steam and oxygen. Fortunately, Engineer Officers were among the first to visit the German Experimental Works at Kiel and preserved the material and personnel.

I would like to stress that this propulsion scheme is very much in its infancy. Hydrogen Peroxide is extremely unpleasant and dangerous to handle although it is the least unpleasant of the oxygen carriers so far examined. When it is realised that the consumption of peroxide is very expensive, and that the precautions to be taken with its manufacture, storage and transport are more rigid than those for cordite, it will be appreciated that there is every need to look for alternatives. This problem will come within the scope of the Marine Propulsion Committee.

Catapults and Accelerators

As an illustration of the specialised auxiliary machinery field I have chosen the subject of catapults and accelerators.

At the outbreak of war, catapults were already installed in capital ships and cruisers, for launching spotting and reconnaissance aircraft. The maximum performance reached by these units was 12,000 lb. weight of aircraft accelerated at 3¼ g to a terminal speed of 60 knots. They were cordite operated. I should mention that very rapid operation was not a staff requirement at this time.

Catapults were subsequently removed from capital ships and cruisers and no further development took place except to meet the special needs of the Battle of the Atlantic. To deal with Focke Wolff Condors, rocket catapults were fitted at short notice in merchant ships converted for launching fighter aircraft. The design of these was not handled by my department, but was a joint effort by D.N.C. and R.A.E. Our part was collaboration in production and trials. These catapults had a performance of 10,000 lb. at 60 knots.

Accelerators are the logical development of the catapult. Those fitted in the old *Ark Royal* at the outbreak of war had a performance of 12,000 lb. at 56 knots and were little more than catapults adapted for carrier use. From these were developed the accelerators fitted in *Illustrious* Class. Though meeting the then staff requirements, further developments were hampered by lack of facilities and also because our aircraft, unlike those of the U.S. Navy, were not specially designed for accelerating. These aircraft limitations entailed a complicated and heavy trolley to allow launching tail-up. This not only put a brake on our own development, but involved considerable alterations to our own accelerators before they could handle American aircraft.

To meet these requirements the units for H.M.S. *Implacable* and H.M.S. *Colossus* were designed to launch both types of aircraft. In spite of the limitations imposed by this compromise it was possible to achieve a launching interval of 40 seconds with perfect drill and a performance of 15,500 lb. at 66 knots or 20,000 lb. at 56 knots. The design and production of the special aircraft required for tail-down launching has now been arranged and the latest accelerators are designed for this method only. The present aim is to be able to launch aircraft from a carrier at sea or in harbour at as fast a rate as possible and to be able to land on, under similar conditions.

Although not handicapped by the necessity for tail-up launching, the general American level of performance has been much the same as our own. Compared critically, their deck equipment has been superior to ours but their below deck machinery placed an inherent limitation on the rapidity of their launching from which ours did not suffer.

It is not without interest that accelerators planned for the *Graf Zeppelin* had a low performance compared with British units, while in Japan no attempt whatever was made to develop carrier accelerators. Once again I must emphasise that our progress has been greatly handicapped by our small facilities for development and it has only been possible to arrange full scale trial after installation onboard. The U.S. Navy has such resources at the Naval Aircraft Factory, Philadelphia. It has now been approved to set up a Naval Section at the Royal Aircraft Establishment, Farnborough, where full scale testing will be carried out in future.

Conclusion

In thus shortly covering a very wide range of engineering activity, in which active development work for the Navy is planned in every field, I may have misled you into thinking that all is now set fair for rapid advances. In the heavy engineering field large advances cannot be made without large resources and I feel it would be improper to leave my subject without a brief outline of what is involved.

We have, in the past, placed considerable reliance on private organisation for research and development in marine engineering. This policy in the early days when the British product was supreme, was extremely fruitful. Under the stimulus of Sir Charles Parsons' genius, British steam turbines and marine gearing led the world. A time is reached, however, in the evolution of the product of nearly every technical conception when continued advance must depend on the cumulative work of research and design teams rather than on brilliant individuals. At the same time, development of such things for war purposes must outstrip other normal commercial advance. At this stage, it is clearly no longer practicable to rely on commercial sources for the research necessary for this development. This principle was recognised as long ago as 1902 when the Admiralty Fuel Experimental Station at Haslar was set up. The advances in boilers, to which I have referred, are a direct result. Similar remarks apply to the British submarine engine and to the Admiralty Engineering Laboratory, West Drayton.

It is clear that the same stage has now been reached in the evolution of naval machinery as a whole, yet our facilities are limited to :

(1) Haslar, which is ill-equipped and under-staffed and it must be a number of years before the new Fuel Experimental Station on the Tyne will be completed and producing dividends.

(2) Admiralty Engineering Laboratory, which also contains electrical and gunmounting sections, is too cramped and lacks adequate facilities.

(3) An interest in P.A.M.E.T.R.A.D.A. for steam turbines, National Gas Turbine Research Establishment for gas turbines, and the Royal Aircraft Establishment, Farnborough, for accelerators.

I fear we shall always have to fight to get a fair share of the facilities of these establishments.

Apart from these we have to rely on industry :—

Messrs. Vickers-Armstrong partnership with Messrs. Craven, David Brown and Muir for gearing.
Messrs. Vickers-Armstrong for High Test Peroxide research.
Messrs. English Electric Company and Rolls Royce for Gas Turbines.
Messrs. Allen, Weir, Rotol and many other firms for individual research and development.

Naturally, we cannot but envy the American Navy their Naval Boiler and Turbine Laboratory at Philadelphia and their experimental station at Annapolis where they are putting up a new big building for housing their future gas turbine experimental plants. There is a further point, even if all the research and testing facilities were available, the acid test is that at sea. Advanced designs need nursing until the teething troubles that only prolonged sea trials will show up are overcome.

I referred earlier to the *Acheron* which was fitted with experimental high pressure temperature steam machinery. She was unfortunately attached to an operational flotilla, tended to be a lame duck, became unpopular and was relegated to duties which only required intermittent running. Had the experimental nature of the ship been recognised, it is possible we might have had high pressure temperature machinery in our ships before 1939.

Earlier in my remarks I referred to two facts which showed a lack of liaison with staff divisions, (1) the selection of 18 knots for our war cruising speed and (2) the selection of 1,000 H.P. for our M.T.B. engines. I feel strongly that unless this liaison is greatly strengthened, we shall continue to guess wrong.

In conclusion, I should like to emphasise the place naval machinery takes in the industrial output of the country. During the war, the horsepower of all but the smaller naval ships and craft totalled 25 million, the aggregate industrial horsepower generated in the country as a whole being some 18½ million. I do not therefore boast when I say that I still believe that a virile marine industry is vital to this country and that it is the proud task of the Navy to set the standard for all to follow.