MAIN MACHINERY

HOW DO WE STAND?

by

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INTRODUCTION

The defeat of Germany has enabled us to find out her strength and weakness in equipment. Our alliance with the U.S.A. has allowed us to see the working of both the minds and the products of her industry. From these two sources we have a background which could scarcely be improved, against which we may and should examine our organisation and equipment, to see what we have to learn, and how we should employ the period of peace ahead.

In this article a small section of this knowledge is surveyed, namely that dealing with the main engines of warships. Owing to the restrictions of our outlook as marine engineers, it is often difficult to assess the true proportions of the problems with which we are faced, and this article is therefore an effort to put in their correct place in the more general picture, the developments in this limited sphere of naval main engines. In order to do this it is necessary to touch on the wider aspects of the energy conversion cycle as a whole, and then to narrow the field to that of the actual main engines.

II. CRITERION FOR JUDGMENT

Two main problems run through all naval developments :—

How to improve efficiency ?

How to reduce weight and space ?

One main condition must be observed, viz. : Reliability must not be impaired, but it should be improved.

EFFICIENCY

Three main aspects must be held in mind when pursuing improvements in efficiency.

(*a*) Thermodynamical.
Possible improvements to the ideal cycle by widening the temperature limits between which it works ; by the addition of heat exchangers ; by the introduction of reheating of the steam in the middle of the expansion ; or by altering the pressure.

(*b*) Practical.
The selection of the most suitable form of machinery. This includes the improvement in design and manufacture of individual parts of machinery, such as the sealing of glands and blading, the improvement of transmission efficiency, and the efficiency of all heat exchange operations.

(*c*) Operational.
The ability to operate a plant at its maximum efficiency is an important part of its ultimate success. It is mainly for this reason that automatics may contribute to the improvement of performance.

RELIABILITY

Reliability is the measure of the extent to which the designer has been able to allow for the actual conditions under which each part of each machine will, in practice, have to perform. It is lost when factors of safety are cut below the margin which must be allowed for one or more of the following :—

(*a*) Ignorance of the actual stresses applied owing to stress raisers, vibration, difficulty in calculating the actual conditions pertaining, or ignorance of the distribution of stress.

(*b*) Variation in the homogeneity of the materials used and hence variation in the properties of the strength members.

(*c*) Variation in the standard of manufacture of parts and their assembly.

(*d*) Corrosion or additional stresses due to operational difficulties.

WEIGHT AND SPACE

The importance of these aspects varies with the class of ship, treaty limits and so on. It is fundamental to warship design, however, that any saving of space in particular, is of benefit to the ship as a whole. These savings must, therefore, be treated as a primary object of development.

III. WARTIME STAGE OF DEVELOPMENT.

(A) THERMODYNAMICAL EFFICIENCY.

Steam conditions

In power stations the highest steam conditions of temperature and pressure which can as yet be regarded as normal are 925°F. and 1250 lbs./sq. in.

Conditions in use in the three Navies are :—

U.S.N. (All classes) ...	650 lbs./sq. in.	825°F.—850°F.
Germany Navy (All classes)...	1,200 to 1,000 lbs./sq. in.	800°F.—840°F.
R.N. (Cruisers and above)	400 lbs./sq. in.	700°F.—750°F.
Destroyers	300 lbs./sq. in.	630°F.—650°F.
Battle Class ...	400	650°F.
Weapons Class ... (1942 Programme)	435	750°F.
Daring Class ... (1944 Programme)	650	850°F.

The gains in steam and fuel consumption which can normally be expected in practice from increased steam conditions have been well established by experience in power stations. They amount to about 10 per cent. per 100°F. rise at 700°F. falling to about 6 per cent. at 900°F. for steam and about half these amounts for fuel.

Increase in pressure is less easy. Here the effect is to increase the wetness of the steam at the end of the expansion ; to increase the leakages from glands and dummies, etc. ; to reduce the specific volume of the steam and so the sizes of pipes, boiler drums, etc. ; and to increase the available heat drop. It is therefore only by a balance of the losses and gains accruing from each of these factors that the best pressure for any given temperature and lay-out of main and auxiliary machinery can be obtained. Any departure from this pressure will give less economy, but the fall on either side is fairly gradual.

The actual consumption (lbs./S.H.P./Hr.) for the Navies were as follows :

	Fuel for Ship Overall		Steam for Main Engines	
	Full Power	20% F.P.	Full Power	20% F.P.
U.S.N.—average for all classes...	.64	.65	7.0	7.0
German—Z class destroyers ...	.78* 1.15†	.95* 1.25†	7.2	8.2
Royal Navy				
Cruisers	.73	.94‡	7.8	8.9‡
Battle Class	.76	1.0	8.35	10.0
Weapons Class (design) ...	.66	.845	7.8	9.0
Daring Class (design) ...	.6	.655	7.03	6.8

* Estimated by designers. † Estimated from trials. ‡ Using cruising turbines.

It is obvious that while the U.S.N. has achieved the gains expected from their adoption of higher steam conditions, something went seriously wrong with the German attempt. The pressure is, perhaps, on the high side, but theoretically this should not result in such poor figures. We shall have to examine the practical aspects of efficiency to find the answer.

Vacuum

This determines the lower limit of the cycle. It may be influenced by the wetness of the steam at the end of the expansion, but in general for naval condensers it is determined by the size of the largest one that can reasonably be fitted in the available space. Thus we find that although the U.S.N. and ourselves specify different vacua at different sea water temperatures the results in cooling surface, etc., are very similar for comparable vessels.

The Germans, however, were not concerned with tropical performance, while they had high wetness of steam at the end of the expansion so that they could afford to have slightly smaller condenser surfaces, and lower vacuum. Also they placed greater emphasis on saving of space than economy.

Heat exchangers

The feed systems used in the three Navies were fairly similar. Both the Germans and the U.S.N., however, used a de-aerating tank into which the feed water is pumped by the extraction pump, and where it is heated by auxiliary exhaust and de-aerated under pressure, before being pumped by a boost pump into the suction of the feed pump. It is claimed that this is the only method by which corrosion of the economisers and boilers can be prevented. In addition both navies used a second stage of feed heating. For this purpose the Germans used live steam in destroyers, while the U.S.N. used steam bled from the turbines. Economisers are fitted by the U.S.N. and are responsible for an increase in efficiency of the cycle between 4—10 per cent. compared to our own present cycle. The Germans fitted their live steam heaters originally in conjunction with Benson boilers operating at critical pressures. This experiment was a failure but they kept the feed system the same. They agree that this was a very wasteful method of feed heating. The U.S.N. have experienced difficulty with the operation of bleed feed heating in the wartime conditions of operation, and it is probable that they will either abandon it or have to adopt some form of automatic control.

The basic and successful differences which we must seriously consider are the adoption of the de-aerating feed tank and the economiser. The latter only has so far been accepted for future construction in the Royal Navy.

Steam to auxiliaries

The U.S.N. use desuperheated steam for their auxiliaries. The Germans used the full steam conditions. Both use about the same exhaust pressures as our own. Here again the problem is probably mainly a practical one. High conditions will enhance the efficiency of the auxiliary if it can be designed satisfactorily for them. The high temperature of the exhaust presents a problem in its efficient disposal. On the other hand the desuperheating of large quantities of steam also involves some practical complication.

Summary of problems on thermodynamical efficiency

We see, then, that the problems before us which must be tackled before a logical step in development can be made are as follows :—

(*a*) What is the maximum temperature which the present state of metallurgy will allow us to adopt (superheater tube, steam pipe, turbine nozzles, etc.) ?

(*b*) What is the appropriate pressure for the type of layout and power we envisage ?

(*c*) How should the auxiliaries be powered ?

(*d*) What heat exchangers will give the best compromise of weight, space and efficiency ? (Economisers, air preheaters, feed heaters, gland steam exhaust condensers, etc.)

(*e*) What vacuum can be obtained in the space available ?

While endeavouring to improve efficiency the effect on weight and space and on reliability must be considered.

Reliability

To ensure no loss of reliability the following conditions must be fulfilled :—

(*a*) Creep characteristics of the materials used must be established.

(*b*) The thermal stresses involved by the use of higher temperatures must either be calculated or established by experiment.

(*c*) The specifications and methods of inspection of materials used must be adequate to ensure that a uniform standard can be depended upon.

(*d*) The necessary measures are taken to prevent rapid corrosion of parts.

It will be readily appreciated that these measures involve a long term development policy needing a considerable amount of both practical and theoretical research.

Weight and space

Increase in steam conditions tends to reduce weight and space, mainly because they reduce specific consumption and hence the sizes of steam drums, pipes, the amounts of oil and water to be pumped to produce a given power, and so on. But just as we have seen that increase in steam conditions alone does not necessarily give the required efficiency, so we must look to the practical side as well to achieve savings in weight and space.

The length of engine room and boiler room spaces in destroyers of approximately equivalent power is about 30 ft. greater in the Germans' than in the U.S.N. ships. The Germans' main reason for the adoption of high pressure and temperature was to save space, which they desired to use for U.W. protection. Their failure to equal the U.S.N. savings in space and the fact that their endurances were no better than our own, for as much fuel stowage, is the best illustration of the enormous importance of the " practical " as opposed to " thermodynamical " solutions to the problem of efficiency and weight and space.

(B) PRACTICAL METHODS OF ATTAINING HIGHER EFFICIENCY

This covers an enormous field and here perforce the discussion must be restricted to the main engines. In order to see naval developments in their true perspective, we must first consider how they differ in essentials from the general problems of turbine design.

Land power stations

The difference in the development of turbine design for power station and naval purposes is fundamental. The power station machine is a constant speed machine. It can therefore be run at a speed higher than its rotor whirling speed. This means that a power station turbine can be of considerable length. Its speed is a multiple of the cycles/min. of A/C which it has to produce, and is therefore limited to large intervals. The naval turbine must operate at any speed and may not therefore exceed the whirling speed of the rotor. It is usually geared, however, and its full speed may be chosen at random.

The efficiency of a turbine depends on the ratio of blade speed to steam speed in each stage. The work done in each stage varies as blade speed and steam speed. Hence the number of stages in a turbine required to give peak efficiency depends on the blade speed. The higher the blade speed the greater the work done per stage, the greater the heat drop in the steam per stage, and hence the fewer the stages required to expand the steam.

Therefore when a rise in pressure and temperature is contemplated, involving a higher total heat drop, it, in turn, necessitates either a higher blade speed or more stages in the turbine.

In the land plant this presents no difficulty. Extra stages can be incorporated. It is necessary to keep the H.P. turbine small to prevent distortion troubles, but since the turbines are usually on one shaft it is of no consequence where the stages are added, as distribution of power between the cylinders is of no importance.

In naval turbines the full speed must be about 25 per cent. below the whirling speed and so they must be kept short. Moreover, the power must usually be shared fairly evenly between the pinions. This means that the turbine blade speed must be higher or that the stages must be divided in several turbines, if higher steam conditions are to be adopted, and at the same time the efficiency maintained.

Naval turbines

Apart from the differences in the conditions obtaining in land and marine turbines which are outlined above, the fundamental differences between the marine turbine of the Merchant Navy and that of the Royal Navy is that whereas merchant ships expect to operate at about their maximum speed throughout their passages, naval ships even in wartime require their maximum endurance at under half power. To achieve this even more stages, which can be by-passed at full power, or below, are required, so that the ratio blade speed to steam speed will be at its best at low powers.

To achieve greater blade speeds it is obviously desirable to increase the R.P.M. rather than the diameter and so keep the sizes and weights small. Moreover it is necessary to keep the rotor small for reasons stated below.

Limitations to R.P.M. and blade speeds

The stresses in our present design of rotor will not allow an increase in either temperature or blade speeds to be made, owing to the danger of the shrunk joint becoming loose (as happened in *Acheron*), and the limit on the stresses near the impulse wheel being reached. The only alternative which is adequate for the step-up in stress which is required, is the solid forged drum. Having accepted this change the only limit on the rotor speed is the strength of the rotor. Hence to obtain the best results we must adopt the alloy which will allow the highest stress at the required temperature. The chief difficulty in this is the size of the forging which considerably restricts the field of alloys that can be used.

Both the Germans and the U.S.N. adopted alloy steel rotors in 1933-37.

Freed from this initial limitation on blade speed, the next one that is met is the limit imposed on r.p.m. by the gearing. Here the size of the gear wheel is limited by the size of the ship. The size of the pinion, and hence the ratio of reduction is limited by the necessity to keep it of ample diameter to avoid excessive deflections due to torsion and bending under load, which would result in failure to distribute the load along the teeth.

There are therefore two possible courses open to us :—

(i) To reduce the load per pinion by splitting the turbines into more than two ; to increase the propeller r.p.m. and to use every possible artifice to limit the pinion deflection, such as three bearing pinions ; the cumulative effect of these measures being to allow of fairly small high speed turbines being used.

(ii) To adopt double reduction gearing, retaining the two turbine arrangement, and using the highest r.p.m. which the available materials allow.

The choice obviously hinges on the reliability and the weight and space consumed by the D.R. gearing. This will be dealt with later. Let us first look at the results of choosing each of these paths. We have them well illustrated by the developments in each of the navies under discussion.

German machinery : single reduction gearing, three ahead, two astern turbines

The H.P. turbine rotor was a solid alloy forging, the I.P. and L.P. were sometimes solid, sometimes bolted forgings. To obtain economy at low power the H.P. blade path was split into two parts. These could be operated in parallel at high powers and in series at low, with an ingenious arrangement of nozzles and bypass valve to maintain as level a consumption curve as possible. It was impossible, however, to fit the three turbines round the gearwheel, so that in destroyers they were spread by placing idler gears between the pinions and the gearwheel for the H.P. and I.P. turbines. In larger ships and in some destroyers the L.P. was put on the opposite side of the gearwheel to the other two. The H.P. astern turbine was mounted on the same shaft as the H.P. or I.P. ahead.

The resulting arrangement is somewhat clumsy, the complication of pipes, valves, etc., being formidable, and the weights poor.

Nor are the prospects of further developments along these lines encouraging. Each rise in heat drop involves more stages or alternatively higher propeller r.p.m. (since the ratio of reduction cannot be increased). For sets of high power (above 40,000 s.h.p.) the problem of space occupied by three turbine sets becomes critical, as also does the problem of propeller revs., which would normally be lower than 300 per min.

In fact by adopting this course the losses in glands, crossover pipes, idler gears, propeller, etc., are all enhanced. The final result is likely to be, as it was with the Germans, that the gains due to the rise in temperature and pressure are squandered, both in efficiency and in weight and space. Gains in efficiency at low powers are only possible at the cost of weight and space.

U.S.N. machinery : double reduction gearing, two turbine sets

Here the complication, added weight and space of the gearing, and its lower efficiency of transmission, is accepted.

This allows liberty of choice of both the propeller r.p.m. and the turbine r.p.m. within the limitations of materials. The rotor r.p.m. and diameter are put as high as centrifugal stresses allow. This had a cumulative effect as the higher the r.p.m. the smaller the rotor, therefore the smaller the diameter of the glands, the lower the losses, and so on. Not only, therefore, is the immediate prospect of reduction in consumption, weight and space, impressive, but the development of further savings is dependent on the technique of producing alloy rotors of the required properties. This is a subject of such fundamental importance, for both steam and gas turbines, that it is hardly possible that it can be left static. As it becomes possible to deal with higher temperatures and the cycle efficiencies improve, the sizes will become even smaller. As the rotor sizes decrease the use of better alloys becomes easier.

The loss of efficiency in the gearing due to the second train approximately doubles the inefficiency of the gearing, i.e. raises it to a total of about 3 per cent. at full power. This is counterbalanced by a gain of 10 per cent. at full power and up to 20 per cent. at low powers in the consumption, so that from consideration of efficiency this is unquestionably the better solution.

Other aspects of " Practical " efficiency

Above we have dealt with the major lines on which efficiency of steam plant must be pursued. Apart from these, however, there are many small improvements which may be made, the cumulative effect of which may be considerable. For instance, one of the leading British " land " firms claims that in ten years it made an improvement of 10 per cent. by such means without any major alterations to their design. Such measures include extra sealing strips for blading, the reduction of clearances, the improvement of gland sealing, and refinements in the design and manufacture of all parts.

The adoption of such refinements in marine turbines has been a matter of experience and judgment in this country. In the U.S.A. and in Germany adequate facilities exist to prove the effective gains due to such things, ashore, before they are fitted to ships. (With the formation of THE PARSONS AND MARINE ENGINEERS TURBINE RESEARCH AND DEVELOPMENT ASSOCIATION it is to be hoped that we shall be able to test our machinery adequately ashore in future.)

Summary of problems on practical efficiency

It is, of course, quite impossible in practice to divorce consideration of the practical and the thermodynamical side of the development of efficiency. This summary must therefore be taken in conjunction with that on page 69. We are faced, then, with the solution of the following :—

(*a*) Shall we adopt double reduction gearing ? From the efficiency point of view the answer is unquestionably "Yes." The decision rests then on reliability and weight and space.

(*b*) Shall we adopt alloy steel rotors ? Again reliability of the British product is the only aspect to be established.

(*c*) What stresses can we use in the rotors at the temperatures that have been adopted ? On this will depend a whole host of results in weight, space, consumption at high and low powers, etc. It is therefore of first importance.

(*d*) What refinements are worth while ?

It is plain from the above that reliability and space play a major part in the decisions which must be made.

Reliability

(*a*) *Gearing*. In the 1920s a great deal of attention was directed to the failure of sets of double reduction gearing in merchant ships. Since this, however, the causes of these failures have been established, and the design of such sets can be made with confidence. The whole onus of achieving reliability in any type of gearing now rests with the manufacture. The U.S.N. have had nearly ten years of satisfactory experience, but latterly, at any rate, their standard of finish has been much higher than our own. The improvement of gear cutting machines is a highly specialised research problem, which is once more being tackled intensively in this country as well. There is therefore no reason why we should fear double reduction gearing if these efforts are maintained.

(*b*) *Rotors*. The production of rotors in this country to perform the duties required in the U.S.N. wartime machinery offers no difficulties. Future improvements can only be secured by research.

(*c*) *Stresses*. For the first step up to 850°F. we have an enormous amount of data already available. But for future steps research will be required to establish what stresses due to differences of temperature and other incalculable conditions exist in rotors in addition to the centrifugal stresses.

(*d*) Having disposed of the dangers to reliability owing to design ignorance, it is essential to ensure that the manufacture is of a sufficient standard to stand up to the new and arduous duties which each part will be performing. The present standards fall a good deal short of the minimum required for safety. Inspection systems for materials are already effective in ensuring a reasonable freedom from failures in major parts. The accuracy of the manufacture, however, is almost entirely dependent on the integrity of the workman. The standard of finish rests generally on the discretion of the overseeing staff. With the change of conditions and stresses these safeguards are not sufficient, and the inspection must be of a standard approaching that of the aircraft industry. This will ensure at the same time that parts are interchangeable between firms—a step which was long overdue.

Such measures will also require the extensive use of jigs and the replacement of antiquated machines in the firms.

This, then, is the programme for the realisation of reliability, upon which we have already embarked.

(*e*) *Impulse and reaction turbines*. It is interesting to note that both in the land turbine industry and in the German and U.S.N. impulse turbines have almost wholly ousted reaction turbines for the H.P. turbine for high temperature sets. This is entirely on grounds of reliability, one of the main disadvantages of the reaction turbine being the large mass of metal in the solid drum rotor, which is slow to reach a uniform temperature under changing conditions.

(*f*) *Refinements*. The question of refinements is one which demands research ashore to prove the practicability of these before either a dangerous machine is sent to sea or before an attitude of safety first becomes exaggerated due to ignorance of the effect of such measures.

(*g*) It is interesting to note that German ships seem to have suffered from considerable trouble with turbine blading and also with auxiliaries.

The latter was quite patently the effect of following the dictums of scientists without sufficient attention to the practical requirements of ship's machinery, in spite of very good research facilities ashore.

Weight and space

(*a*) The demands for higher powers in ships are ever insistent. In the present large aircraft carriers and battleships we have, however, come to the limit of what can be achieved with two turbines and the present steam conditions. The size of the set for, say, 50,000 S.H.P. using single reduction gearing is to our present standards (enlightened as they are by the knowledge of the size of machinery of this power in the U.S.N.) nothing short of monstrous. The most eloquent proof of the Germans' failure to appreciate the true proportions of the naval problem is the fact that, although the primary reason for their adoption of higher steam conditions was the saving of space, they were satisfied to retain single reduction gearing and so accept the vast losses in space which this implied.

(*b*) It is, of course, inevitable that the second reduction should increase the length of the gearing itself. This can be mitigated considerably by the adoption of the "locked train." This consists of splitting the train into two after the first pinion. For a two turbine set the primary pinions drive two primary wheels each. These four wheels are coupled to four secondary pinions, all of which drive the main gearwheel. The loading per tooth is thus halved throughout. Since there is an approximately standard loading per inch length of teeth, this means that the length of each helix can be much reduced.

The next step in saving length of the gearing is to put up the loading per inch length of tooth. At present this is entirely dependent on the accuracy of finish of the gears being improved. As yet the finish is such that the whole load is frequently borne by comparatively few and sometimes widely separated high spots. The task before us then is firstly to improve accuracy of hobbing, and then concentrate on surface finish to try to attain film lubrication. When this state of affairs has been remedied further increases in loading may be possible by consideration of the geometry of the teeth, but so far the attempts in this direction have mainly been fruitless owing to the poor surface finish of the teeth.

(*c*) *Condensers*. Apart from the gearing the other feature which governs the size of the engine room space is the condenser. There seems to be little prospect at the moment of being able to reduce the surface required per pound of steam to be condensed. The only way then open to make it smaller is to reduce the amount of steam to be condensed. This implies an improvement in the cycle efficiency.

(*d*) The reduction of sizes then depends, like efficiency, on the careful working out of the effect of the possible lines of development ; the adoption of the most favourable ; a stepping up of the research into, and the control of, the methods of production to suit the better requirements for standards of finish ; and the steady pursuit of research into detail as well as the next step in raising the Plant efficiency and so reducing the consumption.

C. OPERATIONAL EFFICIENCY

The extent to which devices for improving efficiency such as cruising turbines, nozzle valves, and other hand operated controls, are actually used must depend, in wartime, on the discretion of the Engineer Officer. Frequently the time lag in operation cannot be accepted so that it is impossible to obtain the designed efficiency. This may be overcome by the introduction of automatics, as in the German Navy, where the whole plant was self adjusting to the position of the throttle wheel which operated the nozzle valves. Alternatively the plant itself may be simplified, and this may involve loss of efficiency. Reliability is usually the reason for rejecting automatics, but in the case of the Germans weight and space were also considerably affected. The automatic operating gear added to the machinery two oil pumps to each space and a considerable panel of servo pistons and valves in each boiler room. Besides this it involved an oil burning arrangement which was inefficient at low powers. For the natural circulation boiler this seems slightly fantastic, but we must always remember that it may provide valuable experience for the time when automatics become a necessity with the adoption of forced circulation boilers and possibly for the combustion control for gas turbines. Here it is reliability itself which demands their use.

The best method of improving operational efficiency is by the simplification of controls rather than their complication. Of such is the adoption of the cam-operated nozzle valves. This is the control of the turbines by a handwheel, which operates the nozzle valves in turn, and the elimination of the manœuvring valve as such. Here the equipment is no more complicated than the original while the operation ensures the efficiency being obtained with far less effort.

It is impossible to generalise about the use of automatics. When they are obviously required to preserve reliability, then all the problems that stand in the way must be solved. The development of an efficient feed regulator provides a good example. For the improvement of operational efficiency, each new proposal must be judged on its merits. This latter requires an outlook and judgment based on operational experience at sea. It seems highly probable that the Germans' apparent love of ingenuity for its own sake was the result of their design staff being under civilian control, with little or no representation of sea trained Engineer Officers.

Summary of the war-time stage of development

The Royal Navy had retained the standard lay-out which proved its reliability during the first World War. This had been improved as far as it could be without research.

The German Navy, in search of saving in space adopted high steam conditions. Owing to their failure to use double reduction gearing, and to a somewhat unpractical outlook on the design of the machinery itself, most of the possible gains inherent in the higher conditions were squandered. At the same time a highly ingenious system of automatics and other clever devices had been developed, showing that the designers were not at all lacking in skill, but that there was an unclosed gap between the scientific outlook of the research staffs and the practical outlook of the user.

The U.S.N. adopted double reduction gearing, and higher steam conditions. They stepped up their research effort to meet the requirements of reliability. They also instituted a drive in the manufacture to get better standards and to eliminate those firms whom they could not trust in this respect. The result was unquestionably superior to the main engines produced for any other navy. Moreover they had enough manpower to enable them to continue research for the next step throughout the war. The organisation of their research and design departments, unlike that of the Germans, was and is manned by a high proportion of naval officers, and the control is entirely in naval hands. These officers have in general a higher degree of specialisation in their particular subjects than our own officers who serve in the Admiralty.

In the 1944 Programme Fleet Destroyers (*Daring* Class) we shall have the equivalent of the U.S.N. war-time destroyers, from the point of view of main machinery. It is to be expected that they will embark on further advances soon however.

IV. THE FUTURE

This very brief survey of the problems of advancing in the design of warship machinery, and of the results of the developments which have taken place since the end of the first World War, serves to show the tasks ahead.

We left the first World War with a Navy supreme in its state of development of warship machinery. This had been achieved by the country's industry, which was at that time ahead of the rest of the world. Moreover some of the finest brains in the country were devoted to the production of marine machinery. A steady succession of brilliant ideas flowed into the industry and at that time these were sufficient to keep our Navy ahead of others.

Between the wars, however, the face of the world steadily changed. The stage had been reached where research could not easily be paid for out of the pockets of the firms engaged on the production of an ever decreasing volume of naval machinery. Nor was this money provided by the Treasury.

In contrast, the German Navy equipped all their firms to carry out research and themselves ran a laboratory for steam developments. The U.S.N. had no sharp division between "marine" and "land" firms to contend with. They therefore had the brains of the whole of the boiler and turbine industries to draw upon. Even so they found it desirable to give generous research contracts to many firms and to develop a competitive spirit between firms on the research level. Finally they found it necessary to build a fine laboratory for purely naval research into steam propulsion. Until the start of the war this was not in existence, so that we still have this added source of development to contend with. We may be sure that the Russians will not spare expense to build up even more lavish establishments to bring their Navy into being as they realise the force of sea power in the world.

If we are to regain our position of supremacy in the field of naval machinery (and who dares to define a lower aim ?) the task before us is one which requires prodigious efforts. A glance at the summaries of the problems which must be solved to enable each new step to be taken is enough to demonstrate the magnitude of the research upon which these developments depend. Much of it, of course, is undertaken as a normal industrial or national commitment and as such we are dependent on the level of industry in the country as a whole. On the other hand a great deal is of no possible interest to anyone except for naval purposes (even as opposed to merchant). The Admiralty must obviously assume responsibility for this.

As a first step the Parsons and Marine Engineers Turbine Research and Development Association has been formed, with Admiralty support. A second powerful step has been taken in the association of Yarrows with the English Electric Company, who will design turbines for them, and thus bring the brain and research potential of one of the three foremost "land" firms into the marine world.

The *Daring* Class destroyers will be our first ships with the new steam conditions of 650 lbs./sq. in. 850°F. and D.R. gearing. Thereafter it is to be hoped that nothing will stop the steady advance to higher conditions giving greater economy, and reducing weights and spaces. Parallel to this the introduction of gas turbines must be regarded as an imminent rival to the established steam plant. The possible reduction in space from this source is most impressive and there is no doubt that in this direction lies our shortest cut to the supremacy that we have temporarily lost.