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Latest Developments in Reversible Propellers

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This paper is written mainly from the point of view of the propeller designer rather than from that of the operational engineer and it is a general discussion on the merits and demerits of the controllable-pitch propeller. The present position is discussed and a description of the three main types now available, Escher-Wyss, Kamewa and Rotol, is given.

The main advantages and disadvantages of fitting controllable-pitch propellers is debated and the types of craft and engine arrangements for which the controllable-pitch propeller is most suitable are indicated. Also mentioned are some special problems of design such as the efficiency of controllable-pitch propellers, the problem of cavitation, the forces and couples to be overcome by the control mechanism, lubrication problems and the question of repairs.

Recent drawings of each of the three types of propeller mentioned are included together with several diagrams relating to the calculation of centrifugal twisting moments, etc.

Introduction

Marine engineers in this country will have been watching with interest the recent developments which have been taking place in connexion with the design and construction of controllable-pitch propellers for ships, and they will, the author is sure, welcome an opportunity of taking part in a general discussion on the possibilities of improvement in ship performance which may arise from the adoption of screws of this type for merchant vessels. This paper has been prepared mainly from the point of view of the propeller designer, rather than from that of the operational engineer, but in spite of this it is hoped that it may form the basis for such a discussion.

Briefly, the present position appears to be as follows. It is now realized that the controllable-pitch marine propeller offers a very satisfactory solution to the problem which is presented to shipbuilders and engineers by the possible introduction, in the not too distant future, of gas turbines for ship propulsion, in that such turbines must of necessity be uni-directional, and some other means must therefore be provided for reversing the direction of motion of the ship for manœuvring purposes. It is this which has led to the present interest in controllable-pitch screws by most of the large engineering companies which have actively pursued the development of the marine gas turbine, and also to the renewal of interest in this type of propeller by the leading propeller manufacturers, who wish to be in a position to supply such propellers when the need arises. So far as the controllable-pitch marine propellers, which are available at the present time, are concerned, it can be stated immediately that these are a practical engineering proposition and can be made to work satisfactorily under service conditions at sea.

Blade Mechanisms

During the past few years there has been a marked revival of interest in the design of new mechanisms for varying the pitch of the blades of such propellers and a considerable number of new patent applications has been made by various engineering concerns. These have included mechanisms employing rack and pinion devices, worm and wheel gears, epicyclic gears and link mechanisms

Table 1

Type	Escher-Wyss			Kamewa			Rotol		
First propeller supplied	1934			1937			1942		
No. of propellers supplied	42			116			80		
Largest diameter propeller supplied to date	Diameter	s.h.p.	r.p.m.	Diameter	b.h.p.	r.p.m.	Diameter	i.h.p.	r.p.m.
	10ft. 10in.	1,200	125	16ft. 11in.	7,000	110	10ft. 6in.	1,500	140

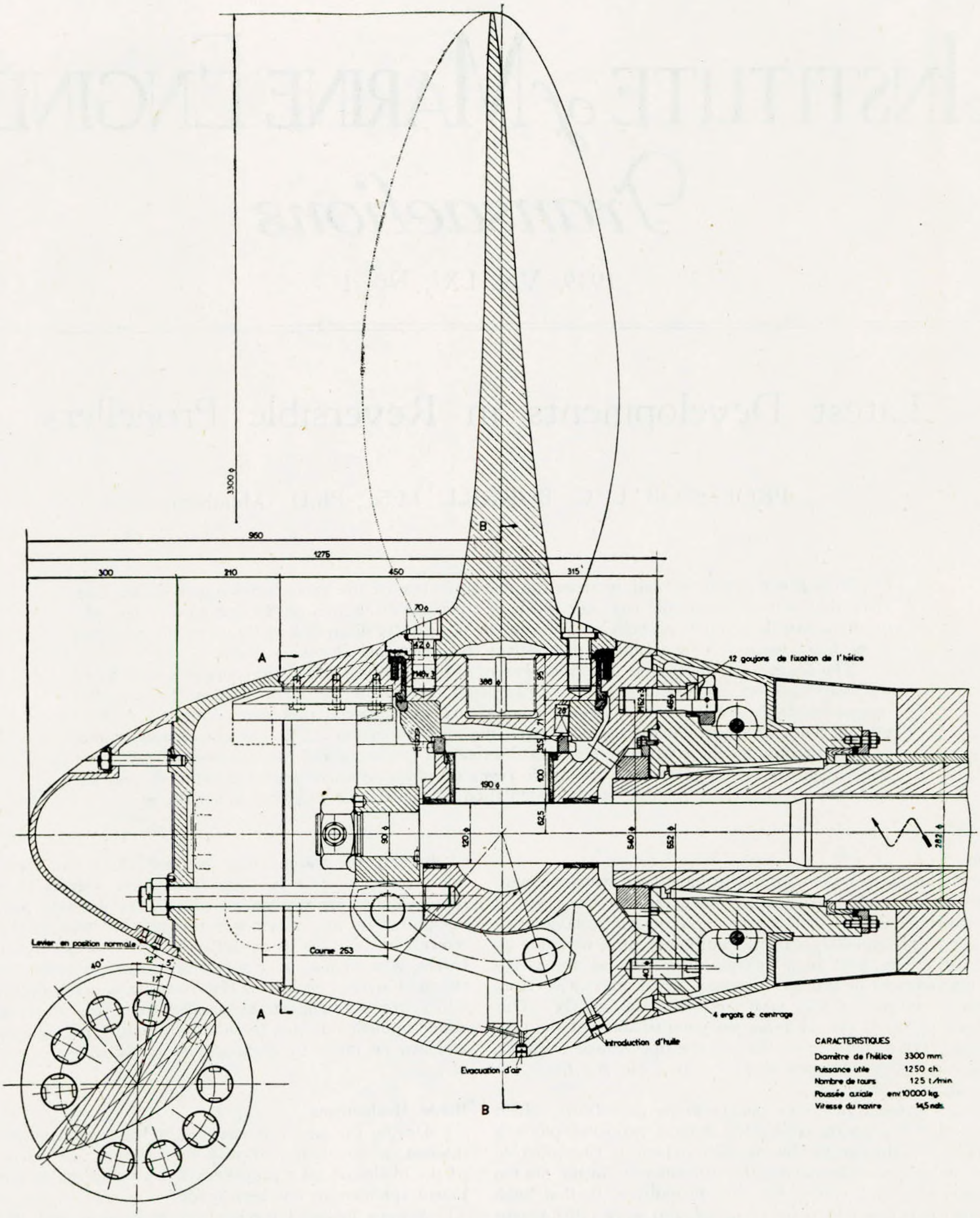

FIG. 1.—*Diagram of most recent Escher-Wyss screw*

attached to the base of the blades, and it is possible that any one or all of these arrangements may be successfully developed when the need for such screws becomes evident. Up to the present time, many of these mechanisms have not passed the drawing board stage, or have not been tried out in service, and it is not considered that a useful discussion of the relative merits of the various types of mechanisms which have been proposed can be held at this stage.

There are, however, three types of controllable-pitch marine screws which have already passed through the experimental stage, and have been proved to be successful in actual service. Two of these have been developed by companies having considerable experience in the design and construction of large hydraulic turbines of the Kaplan type with adjustable blades, while the third, which is of rather more recent origin, has been developed by an airscrew company with experience of controllable-pitch airscrews. They are, respectively:—

(1) The Escher-Wyss propeller—first introduced in 1934.
(2) The Kamewa propeller—first introduced in 1937.
(3) The Rotol propeller—first introduced in 1943.

Since drawings of the mechanisms of all of these screws have already appeared from time to time in the technical press and also in a paper by J. Lockwood Taylor* it is not considered necessary to enter very closely into a detailed description of their

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* Taylor, J. Lockwood, 1946, Proc.I.Mech.E., Vol. 155, p. 211, "The Variable-pitch Marine Propeller".

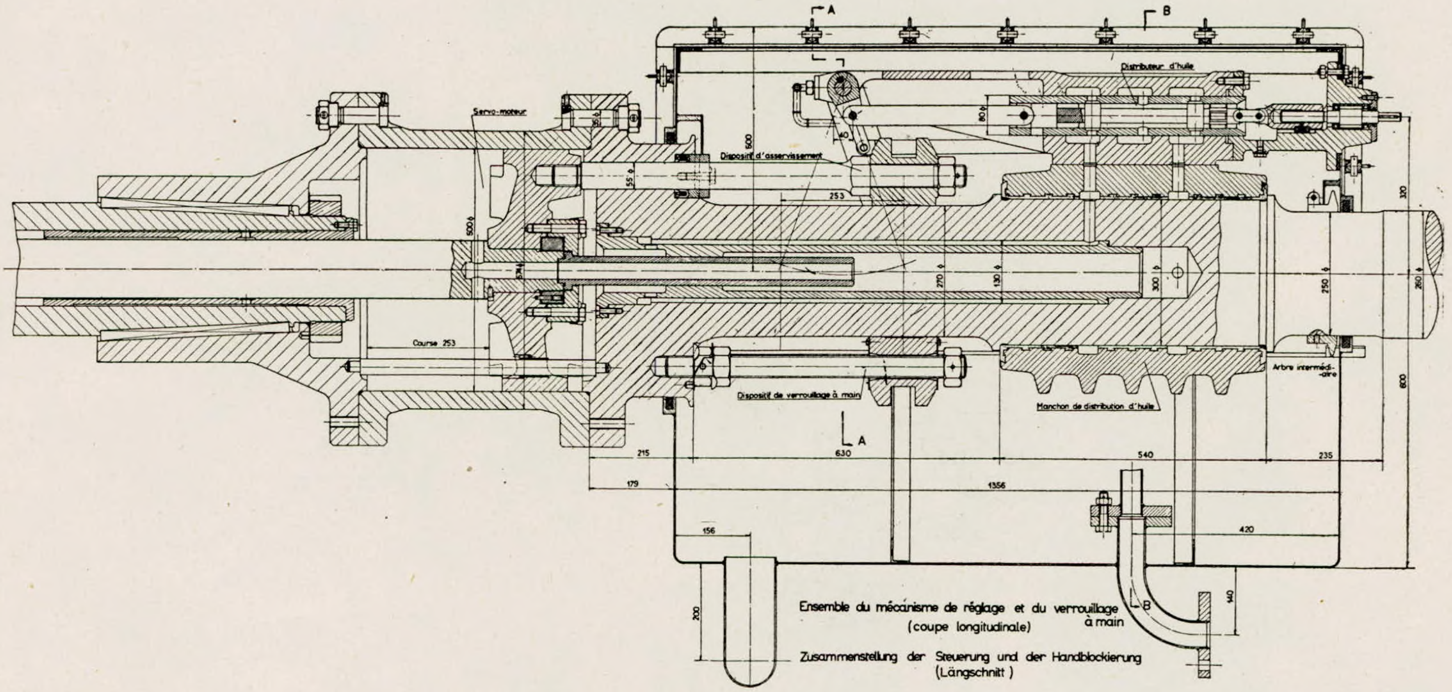

FIG. 2.—*Further diagram of Escher-Wyss screw operating mechanism*

construction. It may, however, be of interest to draw attention to Figs. 1, 2, 3 and 4 which show the details of the largest screws of each of these three types which have been manufactured up to the present time. From these drawings it will be seen that they are all hydraulically operated screws and that the turning of the blades is in each case controlled by means of links attached to the under sides of the flanges of the several blades.

In the Escher-Wyss design, the hydraulic cylinder is located inboard, but in the other two types it is accommodated inside the boss or within the streamline cone cover, which is fitted abaft the main body of the screw. All of these designs require a hollow shaft to be fitted, and this is, in fact, a feature of most controllable-pitch marine screws. The angle of the blades can in each case be varied from the full-ahead position to the full-astern position at any time, with the aid of an hydraulic servo-motor, which can be governed by means of a control situated on the bridge of the ship or in the engine room, as is most convenient. The time to carry out this operation is estimated to be about 60 seconds and the

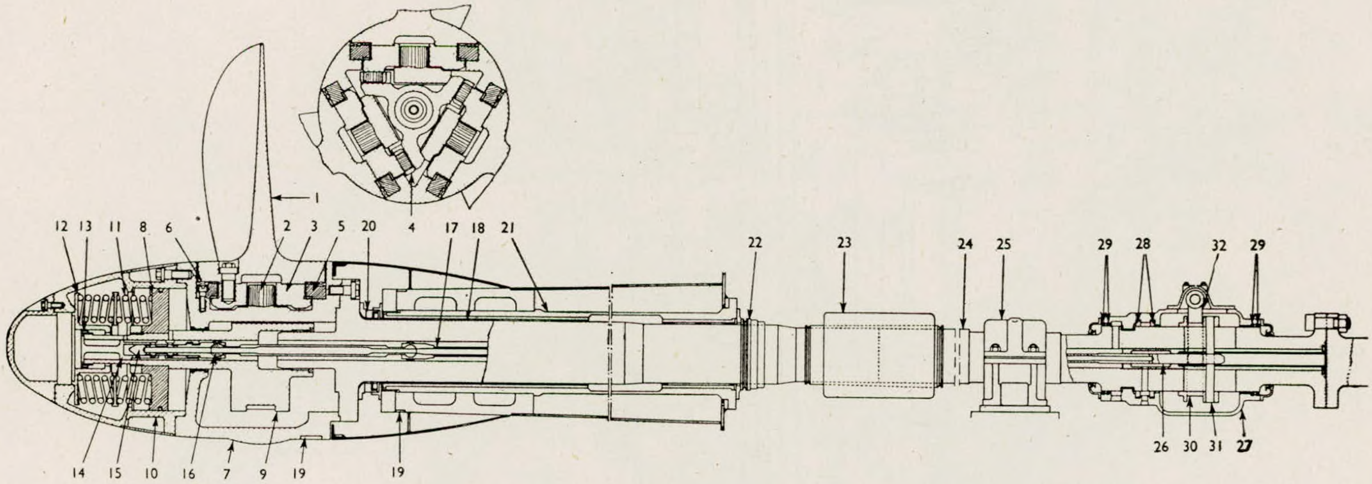

FIG. 3.—*The Kamewa propeller*

1.—Propeller blade.
2.—Centre pivot.
3.—Crank-pin ring.
4.—Sliding shoe.
5.—Bearing ring.
6.—Sealing ring.
7.—Hub body.
8.—Piston.
9.—Piston rod.
10.—Hub servomotor cylinder.
11.—Safety spring. Adjusts blades to "ahead" position if oil pressure fails.
12.—Spring holder.
13.—Piston rod nut for spring holder.
14. Valve liner.
15.—Valve slide.
16.—Ball joint.
17. Valve rod. Hollow for pressure oil to valve.
18.—Propeller shaft.
19.—Zinc ring.
20.—Outside sealing box. "Cedervall".
21.—Stern tube.
22.—Inside sealing box. "Cedervall".
23.—SKF sleeve coupling.
24.—Intermediate shaft.
25.—Bearing.
26.—Valve rod end.
27.—Oil distributing box. For oil to and from shaft.
28.—High pressure sealing rings.
29.—Low pressure sealing rings.
30.—Sliding sleeve.
31.—Sliding sleeve pin.
32.—Levers.

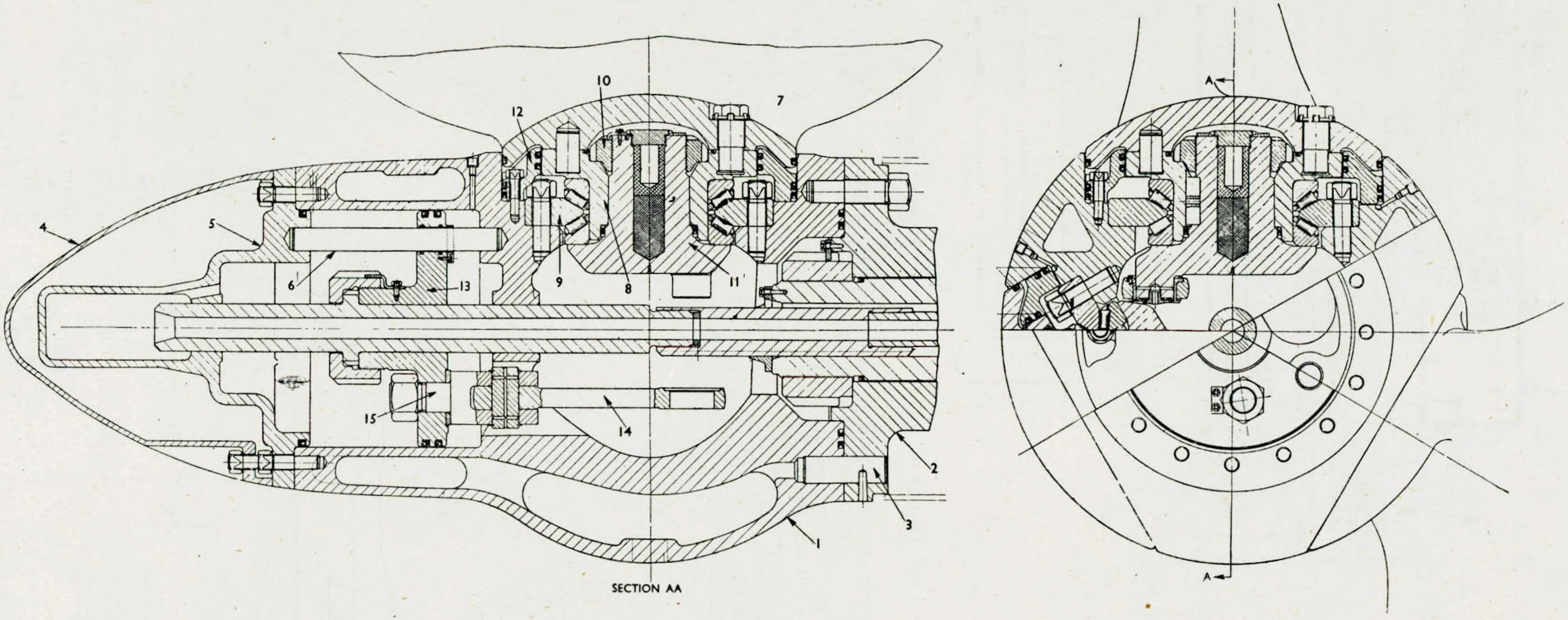

FIG. 4.—*The Rotol design*

1 Propeller hub.
2 Driving flange.
3 Driving dowel.
4 Tailpiece.
5 Cylinder cover.
6 Piston dowel.
7 Propeller blade.
8 Blade bearing sleeve.
9 Blade bearing (taper roller).
10 Bearing retaining nut.
11 Blade operating pin.
12 Blade seal ring.
13 Operating piston.
14 Operating link.
15 Piston eyebolt.

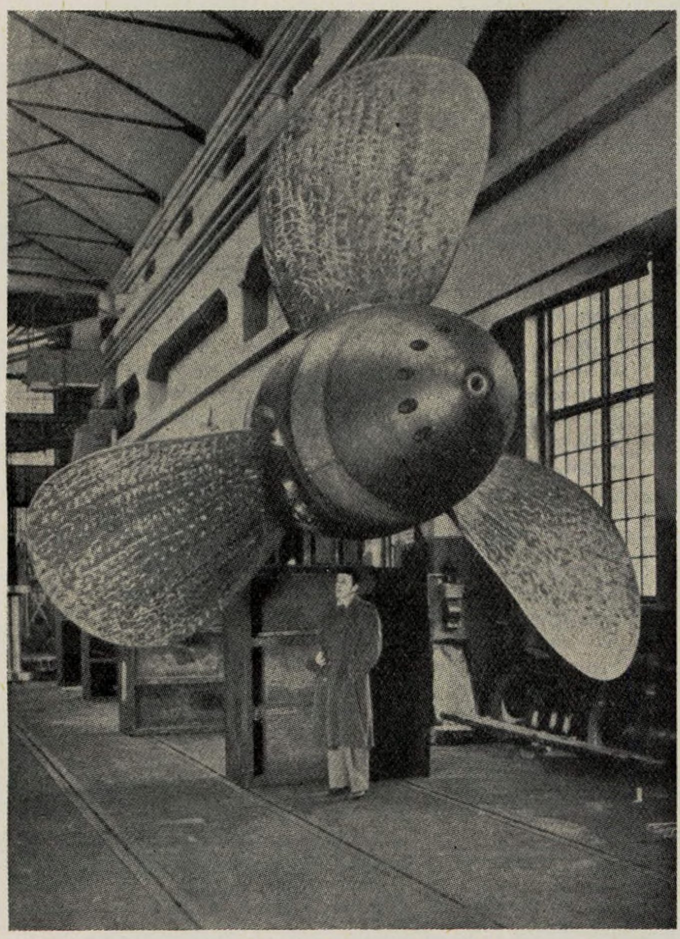

FIG. 5.—*View of one of the latest Kamewa controllable-pitch screws for M.V. "Los Angeles"*

motion from full-ahead to full-astern is quite smooth and continuous and may be interrupted at any stage. The boss-diameter ratio of these screws is from 0·25 to 0·35, according to the type and diameter of the propeller. Figs. 5, 6 and 7 are photographs of the most recent Kamewa and Rotol screws mentioned above, and Fig. 8 is a photograph of a large Escher-Wyss Kaplan turbine runner with adjustable blades. These photographs will serve to indicate the size of marine screws at present available, and also the possible future size of such propellers. Table I shows the number of propellers of each type, which have already been fitted, together with the dimensions of the largest propeller manufactured to date. The author understands that there should be no difficulty in designing propellers of controllable-pitch type for powers of the order of 10,000 to 12,000 s.h.p., which would cover the largest type of propeller required for normal merchant ship practice.

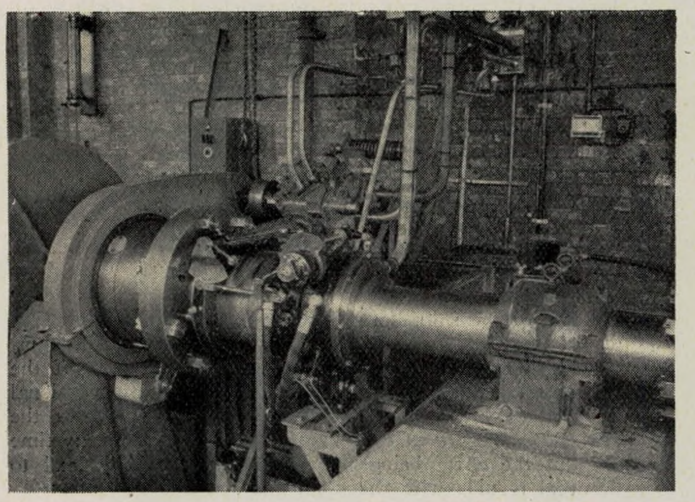

FIG. 6.—*View of the mechanism of the Rotol controllable-pitch screw*

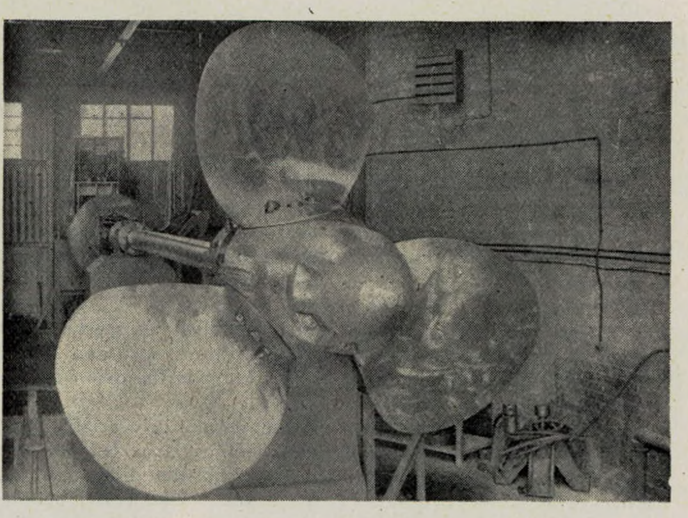

FIG. 7.—*General view of the latest Rotol controllable-pitch screw*

Brief Historical Review

The idea of fitting marine propellers having adjustable blades is not a new one. A number of sailing vessels fitted with the early steam engines and screw propeller about 100 years ago were also provided with devices for controlling the pitch of the blades, and in particular for feathering the blades when the engine was not working. Later, when the marine steam engines became more reliable and of greater power, the controllable-pitch mechanism was abandoned.

There was also a considerable revival of interest in controllable-pitch mechanisms towards the end of the last decade of the nineteenth century, and during the opening years of the present century. This was due mainly to the introduction of the steam turbine and also of the marine Diesel engine, for which the reversing arrangements were at first difficult to provide. The types of blade adjusting mechanisms which were then devised by various inventors are, in fact, not very different from those at present in use, and those who have recently sought new patents for various mechanisms will have realized that this is so, since some of these specifications lie within the period of fifty years, which is covered by the usual Patent Office search. The development of satisfactory reversing gear for Diesel engines and the use of astern tur-

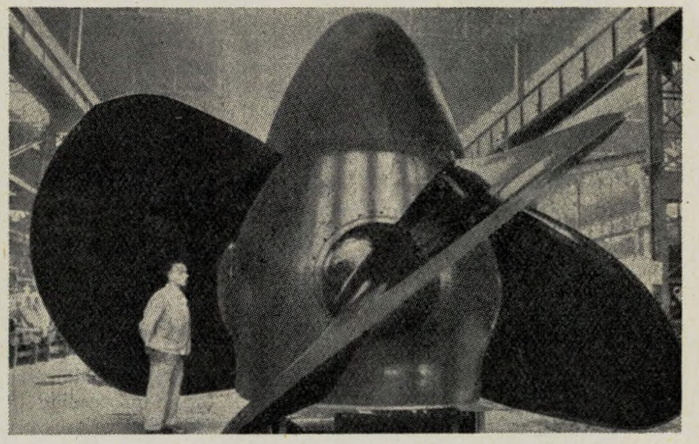

FIG. 8.—*Large Escher-Wyss Kaplan turbine runner with adjustable blades*

bines led to the eventual abandonment or disuse of most of these early inventions, although the use of mechanically operated controllable-pitch propellers and feathering screws has persisted intermittently in quite a large field for small sailing vessels, fishing craft and tugs, since about 1900.

Many of these propellers have continued in operation for very long periods and the fact that they have not been more widely adopted for larger vessels does not reflect upon the satisfactory or unsatisfactory nature of their performance as mechanical devices, but rather upon the fact that the economic advantages to be derived from the fittings of such propellers have so far not justified their initial cost and possible maintenance charges. As will be seen later. the controllable-pitch propeller has special merit for vessels which have to perform several duties, such as those of towing and running free, which do not obtain in the case of large merchant vessels.

A new impetus was given to the design of variable-pitch marine screws by the gradual development of large Kaplan type turbine runners with adjustable blades, and the design of the Escher-Wyss screw for M.V. *Etzel,* a small lake vessel operating on Lake Zurich, in 1934 may be considered to have been the introduction of a new era in controllable-pitch propeller production. This vessel, which was 99-feet long by 15-feet beam, operated on a draft of 4-feet, and was driven by a Diesel engine of 240 b.h.p. running at 500 r.p.m., and it was shown by her performance that it was quite possible to run this engine at a constant speed of 500 r.p.m. continuously without special attention, and to operate the speed control and reversing entirely from the bridge. It was therefore possible to dispense entirely with engine-room staff. This vessel has been in constant service for the past fourteen years and apart from the replacement of one set of blades for each screw has given continual good service.

The main advantages which are to be gained from the adoption of controllable-pitch propellers are, of course, concerned with improved manœuvrability. and with the running conditions of the main engines rather than with the propulsive efficiency of the ship as a whole. This is a general conclusion, based on the practical experience which has been gained on actual installations up to the present time, and this conclusion is quite in line with the deductions which can be made from theoretical considerations. This statement may require some modification for special types of craft which have to operate under widely varying conditions, or which may have a quite unusual resistance curve, such as M.T.B.'s etc., and other planing craft.

Advantages and Disadvantages of Controllable-pitch Propeller Installations

The fitting of a controllable-pitch marine propeller enables the following operations to be carried out, which are not possible with the fixed pitch propeller :—

(1) The vessel may be put astern direct from the bridge, and the speed at any time can be controlled without ringing down to the engine room for a change in engine speed. In certain circumstances this may be of considerable importance, in that the time for a reversal of the ship's direction can be reduced by approximately one third.

(2) The main engine or engines may be arranged to run at constant speed, and the load on the engine can then be varied by means of the propeller. This is of special advantage for small vessels fitted with Diesel engines.

(3) The main engine may be arranged to run at constant torque for varying speeds, or for varying conditions of hull and sea. When a fixed-pitch propeller is fitted to a vessel the torque in the shaft at given rotational speed is automatically controlled by the propeller, which can only absorb a certain torque at given revolutions and speed of advance, and this means that for reduced speeds the mean effective pressure is automatically reduced in linear ratio to the change in revolutions, whereas with a controllable-pitch propeller the pitch of the blades can be increased when proceeding at lower speeds of advance, and the full mean effective pressure of the engines can thus be developed at any time. This may be of advantage for certain types of engines, and this is a matter which could well be discussed by marine engineers.

versing operations by means of the adjustment of the propropeller blades. It is claimed that this should reduce the wear and tear in the engines and thus offset the initial high cost of the controllable-pitch propeller installations.

It will be noted that the above advantages are mainly concerned with the running of the main engines, and that therefore it is very largely for the marine engineer to assess the value of such operational facilities as the controllable-pitch propeller will provide. There are, of course, on the other side of the balance, a number of disadvantages and difficulties which are associated with the controllable-pitch propeller and these, which are concerned mainly with the operation of the propeller as a means of efficient propulsion, or with the general operation of the ship, may be enumerated as follows :—

(1) In order to provide a housing for the mechanism which is necessary for varying the pitch of the blades the boss of the controllable-pitch propeller must of necessity be larger than that of the corresponding fixed-pitch screw. and this inevitably leads to a loss in speed under full load conditions.

(2) The pitch distribution from root to tip of the blades of a propeller is normally chosen to give the most favourable efficiency for the normal full-speed pitch position, but as soon as the angle of the blades is changed, this condition is automatically destroyed, as the pitch of the outer sections, measured in feet, changes at a much faster rate than that of the inner sections. That is to say, as soon as the pitch is reduced, the propeller becomes one which has a linear pitch reduction from the root to the tip and this is, of course, not favourable to the attainment of the highest efficiency.

(3) Owing to the narrower root widths, which are necessary to accommodate the blades on the circular-based flanges. and the thicker root sections, which are necessary to provide the extra strength which is required from the blades of the controllable-pitch propellers, the problem of root cavitation becomes much more critical and must be studied very closely, even for quite normal powers and rotational speeds.

(4) In view of the higher stresses which have to be met by the controllable-pitch blades, and to keep the boss diameter within reasonable limits, higher stresses must be accepted and special materials must be employed for the bolts etc., attaching the blades to the boss. For this reason, repair and maintenance may be somewhat difficult if the vessels are operating at some distance from their normal base, and it would appear necessary to carry spare propellers of fixed pitch type, which could be placed in position whilst the controllable-pitch propellers were being sent back to the manufacturers for repair purposes.

(5) Normal shaft-taper and keyways are not possible with most designs of controllable-pitch propellers. The method of attaching the propeller bosses to the main shafting is there-

(4) There is also the possibility that when operating under heavily loaded conditions, due to fouling of the hull, or increased hull resistance due to weather, the pitch of the propeller blades may be reduced, thus enabling the engines to rotate at a greater speed than that to which they would automatically be regulated by the fixed-pitch propeller, and in this way the engine may be allowed to develop a higher power under these circumstances than would otherwise obtain without exceeding the designed mean effective pressure.

(5) As the engine speed may be varied at will for any speed of advance of the ship, it should be possible to avoid running at or near shafting criticals. This advantage is, perhaps, open to some criticism, as it may also happen that if the control is centred in the bridge, and the question of torsional oscillations is not properly understood by the operators, the critical revolutions may be inadvertently chosen at any time without the effect being noticeable. and this may lead to eventual trouble with the main line shafting.

(6) As most controllable-pitch propellers can also be operated in the reverse position, it is possible to run the engine continuously in one direction only, and to carry out all the re-

fore unusual and may present difficulties where dry dock facilities are limited.

(6) The forces and moments involved in carrying out the necessary pitch alterations when the ship is in motion are high, and there is a possibility of the propeller windmilling or driving the engine under certain conditions. The turning moments on the blades can be reduced by balancing the hydrodynamic and centrifugal moments in the normal working condition, but whilst this tends to make reduction of the pitch relatively easy, it may also have the adverse effect of making the return from the astern pitch to the full-ahead pitch difficult to accomplish.

(7) In controllable-pitch mechanisms of the type employing a link attached to the under side of each blade, and in particular with those arrangements in which the hydraulic cylinder is located within the cone-cover, an uncommonly long length of cone is usually required in order to obtain a satisfactory streamline shape abaft the large boss of the controllable-pitch propeller. This arrangement is quite permissible with twin-screw vessels but requires modifications to the normal stern arrangements in the case of single-screw vessels. It is usually necessary to employ a balanced rudder with a portion cut away to accommodate the long cone, and even so the final arrangement is not as satisfactory as that which would be obtained with a fixed-pitch propeller, having a normal boss to diameter ratio of about 0·18.

Vessels for which the Controllable-pitch Propeller is most favourable

For certain classes of vessels the controllable-pitch propeller is most advantageous, and material gains in power absorption can be achieved. Generally speaking. the types of vessels to which this applies are those which are used for dual purposes, such as tugs and icebreakers. Examples of the types of vessels for which the controllable-pitch propeller is most suitable are:—

(1) Tugs and icebreakers.
(2) Inland water craft such as river boats, ferries etc.
(3) Motor torpedo-boats fitted with high-power Diesel or petrol engines.
(4) Submarines.

and other vessels for which the controllable-pitch propeller may be found to offer some advantage are:—

(1) Trawlers.
(2) Small general coasters.
(3) Cross-channel steamers.
(4) Oil tankers.

Tug Propellers

It is well known that it is impossible to design a fixed-pitch propeller which will be suitable for both the free-running condition and the towing condition for a tug, and this is specially true when Diesel engines are adopted. If, for example, the propeller is given the most suitable dimensions for the free-running condition, then the towing pull which can be developed at the low speeds of advance, which correspond to the usual towing condition, is limited by the mean effective pressure which can be permitted. If on the other hand the screw is designed to give the maximum towing pull at slow speeds of advance, then the revolutions per minute in the free-running condition will be too high and the power which can be developed at high speeds will be limited by the maximum revolutions which can be permitted, having regard to piston speeds etc. For this reason, it is usual to design the propeller to give the correct number of revolutions for the free-running condition with high speed of advance, but to give the blades a much higher surface area than would be required for the free-running condition so that cavitation is avoided when towing. The towing pull which can be obtained and the corresponding rotational speed are therefore limited. With the controllable-pitch propeller, this limitation of pull does not occur, as the screw can be arranged to work at reasonable slips for both the free-running and the towing conditions. When running free, the pitch can be set at the high position, and when towing the pitch can be eased somewhat so that the revolutions are not limited—thus enabling higher powers to be developed and higher efficiencies to be obtained.

Icebreaker Propellers

The case of the icebreaker is very similar to that of the tug in that this type of vessel must be capable of producing a high thrust at slow speed, and also capable of rapid reversal. At the same time, the propellers must be so designed as to obtain the best speed under free-running conditions consistent with the other duties of the ship. The design of controllable-pitch propellers for this type of craft has been the subject of a long series of tests in the Swedish Tank at Gothenborg, and is discussed in a paper entitled "Propellers with Adjustable Blades" by H. F. Nordstrom, published in 1945. The important conclusions reached as a result of the tests were that for most efficient running the propeller should be designed with an initial pitch some 10 to 20 per cent lower than that suitable for the full-ahead condition and the best astern results were obtained from a propeller with plane blades and symmetrical sections. It is also stated that for controllable-pitch propellers it is desirable to adopt a large pitch reduction towards the root for the normal ahead position and that the best astern performance is obtained with adjustable blades and reversing of the direction of rotation.

M.T.B. Propellers

In motor torpedo-boats, fitted with fast-running boosted petrol engines, the major propeller problem is that of cavitation. Such propellers cavitate very considerably if not completely under full-speed conditions, and the pitch given to the screws must therefore be higher than would be the case if cavitation did not occur. At lower speeds cavitation is not present and there is consequently no loss in thrust due to this effect. The propellers are therefore stiffer than necessary for satisfactory working at such reduced speeds. The result is that the boost pressures are high for the lower r.p.m. and in some instances it can happen that this boost pressure exceeds the permissible value before the top speed of the craft is reached, and this difficulty can only be overcome by reducing the speed at which cavitation occurs, or reducing the pitch of the propeller. For this reason it would be desirable to operate such propellers at reduced pitch for the cruising speeds and up to, say, 20 knots, and at higher speeds up to, say, 30 knots, when cavitation is present in ever increasing degree, to raise the pitch of the blades to offset the loss in thrust and torque which accompanies this phenomenon. This is confirmed by the results of exhaustive tests with the Rotol screws, and it has been shown that a marked saving in fuel consumption can be achieved at the cruising speeds, if such a procedure is adopted. Unfortunately, the efficiency of the controllable-pitch propellers and the degree of cavitation present at the highest speeds are influenced unfavourably by the large boss, and the above gain is offset by a loss in speed of about one knot at the full power condition.

Submarine Propellers

The resistance of a submarine in the submerged condition is very much greater for a given speed than that on the surface, consequently, the under-water speed obtainable with a given engine size is much lower than the surface speed. The propellers, therefore, have to work under two very different conditions, and the advantage of controllable-pitch, or at least the possibility of dual-pitch settings, is obvious. The maximum propeller efficiency obtainable under-water is not very much improved by the ability to change the pitch in view of the fixed diameter, but the engine loading conditions are much improved with the reduced pitch setting in the submerged condition, and important savings in fuel may be effected.

Trawler Propellers

The problem of the design of large modern trawler propellers differs somewhat from that of the other dual-purpose propellers discussed above, in that the power required for trawling is considerably less than that needed for the high free-running speeds now obtained by such vessels. Furthermore, although the required diameter for optimum performance in the free-running condition can usually be obtained, the best diameter for the trawling condition very much exceeds that permissible from clearance and draft considerations. The power used when trawling is only about 55 per cent of the full free-running horse-power of the engines, and an increase in towing speed, such as might be obtained with a dual-pitch propeller, is not considered to be of great advantage from the fishing point of view. On the other hand it is possible that the use of a lower pitch when trawling would be advantageous from the point of view of cavitation and blade erosion. At the present time it is necessary to provide such trawler propellers with much larger blade surface area than is necessary for the free-running condition in view of the high loading and high slip when trawling, and with controllable-pitch propellers this blade surface could possibly be reduced with advantage to the free-running speed, at the same time avoiding the effects of surface roughening which now occur. In smaller trawlers and fishing craft of moderate speed, the difference between trawling and free-running power is not as great as that referred to above, and for such vessels there is a possible advantage to be gained from the adoption of controllable-pitch propellers with faster running Diesel engines.

Inland Water Craft

The main advantage of the controllable-pitch propeller for inland water craft, river boats, double-ended ferries etc. lies in the ease of manœuvring, which direct control from the bridge provides. There is also the possibility of a reduction in engine room staff, with engines running at constant speed, and there seems no doubt that there is a very wide field for development in vessels of this type. Small general purposes coasters and cross-channel steamers are not very far removed from this class of vessel, and it would appear that the ease of manœuvring and the possibility of a quick turn-round, which could result from the fitting of controllable-pitch propellers, present distinct advantages, at least for the smaller vessels. There is also the fact that such vessels operate on a fixed route and repair and maintenance considerations would therefore be simpler than for ocean-going steamers.

Merchant Ship Propellers

For the majority of ocean-going cargo vessels the advantages to be derived from the use of controllable-pitch propellers appear to be very small, unless the type of main engine is such that the flexibility of the controllable-pitch drive can be used to obtain some advantage in the engine room, either in the form of simpler engine arrangements, or of a saving in fuel. In 1942, the author examined in some detail the case of a cargo vessel designed for a full speed of 13 knots, with a Diesel engine power of 3,750 b.h.p., the normal propeller speed being 110 r.p.m., and the conclusions then obtained are still valid. With a service speed of 12 knots in good weather, it was found that if the pitch is increased to allow the engine to turn at 86 r.p.m. instead of the 102 r.p.m. at which a fixed pitch screw would have automatically required it to turn, the gain in efficiency was two per cent, and a similar gain was possible at 10 knots, if the propeller speed was reduced to a value consistent with the optimum efficiency setting of the blades. The effect of variations in loading and hull resistance was also examined, and it was found that in a partly loaded condition, representing a decrease in resistance of about 20 per cent, the gain in efficiency is 4 per cent. The result obtained for increased resistance, representing the influence of weather or fouling, was that the possible improvement gradually diminished as resistance is increased, until for a condition representing 30 per cent added resistance the propeller efficiency gain is negligibly small. Details of the calculations on which the above figures are based are given in the paper entitled "Developments in Propeller Design and Manufacture"* and it is believed that this result is now generally accepted by those responsible for the design of controllable-pitch propellers.

The oil tanker which continually alternates between ballast and fully loaded conditions may, of course. be an exception to the above rule, and the possibility of savings in fuel consumption for such vessels is worthy of further consideration, possibly by means of model experiments carried out with propellers having adjustable blades.

The Efficiency of Controllable-pitch Propellers

In order to house the mechanism for changing the pitch of the blades, the boss of a controllable-pitch screw must of necessity be larger than that for the corresponding fixed-pitch screw, and also somewhat larger than that of a loose-bladed propeller. The ratio of the boss-diameter to the outside diameter of the propeller for a heavily loaded fixed-pitch propeller can be as low as 0·12, but the usual value of this ratio for modern fixed-pitch screws for merchant vessels lies between 0·16 and 0·18, and the corresponding value for a well-designed loose-bladed propeller is about 0·25.

In comparison with the above figures, actual designs for controllable-pitch propellers show that it is very difficult to reduce the boss/diameter ratio below 0·28, and more usually this ratio works out at about 0·30 to 0·32 and in some cases is as high as 0·35.

There are three ways in which the effect of this large boss size on the propeller efficiency may be assessed. In the first place by model experiments, secondly by the analysis of voyage data for built propellers and fixed-pitch propellers fitted to the same ship, and finally by means of calculations using the vortex theory.

Published data concerning the effect of boss size on propeller efficiency derived from model experiments is not very extensive. but the information which does exist suggests that the loss in efficiency due to this effect is about 3 to 3½ per cent for a boss-diameter ratio of 0·25 as compared with a ratio of 0·18. The usefulness of such data is to some extent vitiated by the fact that with open-water screws it is usual to fit the screw to be tested in front of the testing boat or test gear, and the effect of the closing in of the streamlines abaft the propeller as normally fitted, is therefore eliminated.

On the other hand, some tests with large boss sizes in the behind condition have been run with bosses built up from the normal diameter without correction of the root blade-widths for the increased diameter, and the results are therefore misleading. The analysis of voyage data for built and solid propellers suggests that the effect of large boss sizes is greater than that given above, and that the loss in efficiency is of the order of 4 to 5 per cent for large bosses with relatively short streamline cones. In some cases the difference is as high as six per cent or more, if the nuts are not well cemented over and streamlined. Unfortunately, the normal vortex-theory calculations do not include any means of calculating the effect of the closing in of the streamlines abaft the screw, and the propeller efficiency is calculated by integrating the thrust and torque grading curves as shown in Fig. 9, from the tip down to the boss radius. Even so, when such calculations are made for comparable designs, and allowance is made for the less favourable root section thickness-ratios and increased blade interference, the results show a loss in efficiency of the order of 2 to 3 per cent. This loss in efficiency, due to the increased boss-diameter, has been fully appreciated by the designers of controllable-pitch propellers and consequently they have been much concerned to reduce this difference to a minimum. The possible causes of this loss in thrust and efficiency are :—

(1) The rapid closing in of the streamlines aft of the boss, and

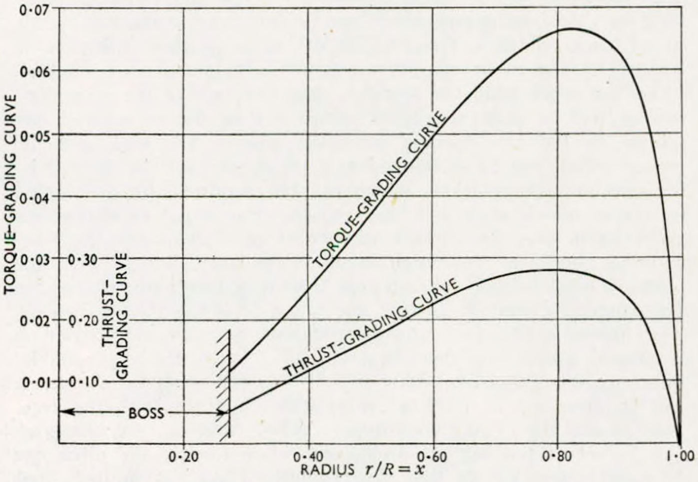

FIG. 9.—*Thrust and torque grading curves for 3-foot controllable-pitch propeller*

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* Burrill. L. C., 1943, Trans.I.Mar.E., Vol. 55, p. 148.

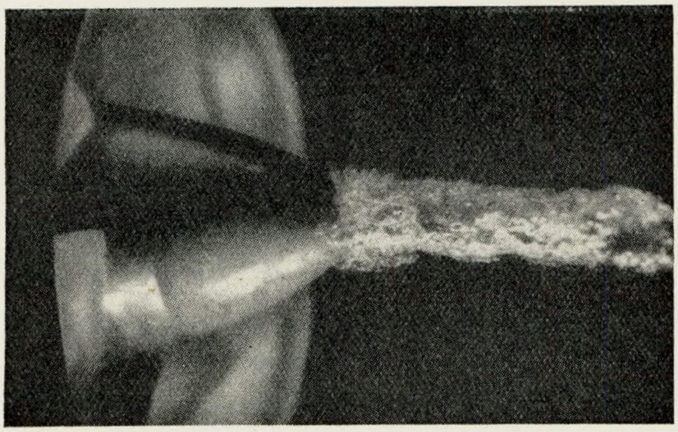

FIG. 10.—*Formation of a vortex core*

possible breakdown of the flow or formation of a vortex-core (see Fig. 10).

(2) Direct increase in boss-drag where the propeller boss diameter is larger than that of the shaft bossing of the ship.

(3) Breakdown of flow on the rear parts of the inner blade sections where the change in curvature is rapid and the root widths are insufficient.

(4) Loss of working blade surface due to the shorter blades.

The first of these causes of loss can be obviated, or at least reduced, by the fitting of long streamlined cone-covers. This is not difficult to arrange in the case of twin-screw vessels, but leads to unusual stern arrangements in single-screw installations. For example, suggestions have been made for the fitting of fairing pieces in continuation of the propeller diameter on the stern frame or on the forward part of displacement rudders of the Oertz type, and also for the cutting away or recessing of the leading edge of balanced rudders. These arrangements are successful in securing the desired stream-line form, but may not be regarded with favour by superintendent engineers who are responsible for the care and maintenance of ships in service.

The effect of having a boss size which is greater than the shaft-bossing can be minimized by the fitting of carefully streamlined ropeguards forward of the propeller or alternatively by the expedient of increasing the diameter of the shaft-bossings above the normal size. This latter arrangement may, however, prove inconvenient if at a later date it is decided to fit an alternative propeller.

If the root widths of the blade are faired into the circular base the inner sections of a controllable-pitch propeller are of necessity narrower and thicker than those of the corresponding solid propeller, but this difficulty can be overcome by allowing the root widths to extend beyond the circular base and to fit closely round the shape of the boss. This introduces the possibility of stress concentrations at the junction between blade and flange, but designs of this kind have already been fitted and have been satisfactory. An alternative solution is to reduce the work done by the root sections by adopting a rapid decrease in pitch towards the base of the blades and employing root sections having very low centreline camber approaching closely to streamline strut shape.

The conditions under which a swirl-core or cavity may exist behind the large boss of a Kaplan turbine runner have been closely studied by Messrs. Escher Wyss and Co., Ltd., and this is the subject of an article by Dr. L. Vuskovic, published in the Escher Wyss News, Vol. xiv, 1941. Briefly, the principle of the conservation of momentum, when applied to the rotational component of the motion in the slipstream abaft the propeller blades, shows that with a large boss and relatively short firing cone, the rotational velocity of the water at the crown of boss radius is very considerably increased as the streamlines passing round the cone occupy an annulus of ever decreasing radius, i.e. $\omega R_1^2 = \Omega r_2^2$

where ω=angular velocity at boss radius R_1

Ω=angular velocity at smaller radius r_2

This is accompanied by a marked decrease in pressure, and a limit is soon reached beyond which a cavity or core is formed, as shown in Fig. 10.

In the case of Kaplan runners working in an enclosed tube a satisfactory solution to this problem has been found by controlling the radial distribution of circulation (i.e. by reducing the pitch of the blade towards the root sections so that the root circulation is zero, or in some cases negative, in value). This principle has also been applied by them in designing the blades of controllable-pitch marine propellers with entirely satisfactory results. Recent tank tests at Wageningen have in fact shown slightly higher efficiencies for such controllable-pitch propellers than for conventional fixed-pitch screws of similar dimensions. It is a little difficult to assess the true value of this result as the blade sections were also of an advanced design, developed as a result of wind-tunned experiments, and the application of such principles to the design of fixed-pitch screws may in view of the smaller boss diameter lead to still higher efficiencies. At the same time this is a notable result and it does indicate that the fitting of a well designed controllable-pitch propeller need not involve any appreciable loss in efficiency as compared with a propeller of standard design. It also introduces a new principle in design which may well be applied to loose-bladed propellers.

That the question of cavitation is very important in the case of controllable-pitch propellers is evidenced by the fact that those firms which have specialized in the design of such propellers have found it necessary to erect their own cavitation tunnels in order to study this problem. In the first place, the adoption of shorter blades means that the thrust per unit length of blade is increased, and this would normally require increased blade widths. In the second place, the thicker and shorter root sections of the controllable-pitch propeller are liable to earlier breakdown than those of equivalent fixed pitch design, and the local peak suctions in this region of the blades are very much increased.

Furthermore, whilst it can be assumed that the sections of a fixed-pitch propeller will be working at a reasonably steady angle of incidence, apart from the effect of local wake velocity variations over the disk, this is certainly not true in the case of the controllable-pitch screw. As mentioned previously, the pitch of the outer sections decreases much more rapidly than that of the root sections when the blade angle is changed. It is therefore possible for the tip sections to be working at slightly negative angles under certain circumstances in the ahead position, whilst the root sections are still working at a positive angle of incidence, and the reverse is true for the astern position of the blades.

As will be seen later, it is important to reduce the blade widths of a controllable-pitch propeller as much as possible in order to avoid high centrifugal twisting moments. This means that the question of cavitation must be closely examined for each radius of the propeller, and, furthermore, that several blade settings must be considered. This problem can be approached either by testing models in a variable-pressure tunnel or by means of vortex-theory calculations. Such calculations can now be used to determine the angle of incidence of each blade section and important suction peaks can be avoided by the use of sections designed to give an approximately uniform velocity distribution over the back of the blades. Such sections have been named "laminar flow sections" by aeronautical investigators, as they can be used to delay the appearance of turbulent flow, and move the point at which transition occurs towards the trailing edge.

For the root or inner sections of controllable-pitch screws, sections of this type with low centreline camber are the most suitable. In designing such sections, it is necessary to take account of the curvature of the streamlines due to blade interference or cascade effect, and since the presence of the adjacent blades tends to increase the negative pressures on the forward parts, it is

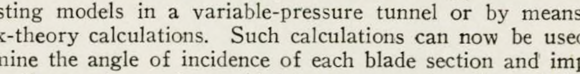

FIG. 11.—*Typical blade root section designed to give uniform suction distribution*

advisable to move the position of the maximum ordinate towards the trailing edge and to use a relatively finer entrance than run. Fig. 11 shows a typical section of this kind which has been used by the author for a number of years for fixed-pitch screws. For the sections in the outer parts of the blades, the effect of blade interference is less than at the root, and here the maximum thickness may be moved nearer to the leading edge, or the fullness of the forward part of the section may be increased as in the N.A.C.A. 16 series type section shown in Fig. 12.

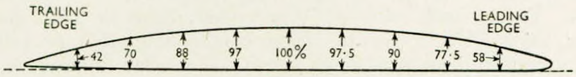

FIG. 12.—*N.A.C.A. 16 Series section, $c/_w=0{\cdot}08$, centreline camber$=0{\cdot}024$*

There is need for a good deal of research both in wind-tunnels and in cavitation tunnels in order to obtain the most suitable type of blade sections for controllable-pitch propellers as, in addition to the question of cavitation at various angles of attack, there is also the problem of reducing the turning moments which have to be overcome by the blade adjusting mechanism to a minimum.

Blade Turning Moments

The blades of controllable-pitch screws may be compared to a balanced rudder in that in the normal working position the centre of pressure, which lies approximately at 0·4 of the blade width from the leading edge at small angles of incidence, can be placed slightly forward of the central turning axis, so that when moving ahead the hydrodynamic turning moment tends to increase the pitch. Owing to the rotation of the propeller there is always a centrifugal turning moment present which tends to turn the blades into a neutral position approximately at right-angles to the shafting, and as soon as the blade adjusting mechanisms come into action there is a frictional moment which always opposes the direction of turning. The problem of the designer is to so arrange these three couples that they tend to balance each other and to minimize as far as possible the circumstances in which they may become additive.

For example, examine briefly what happens when the pitch is reduced with the ship moving ahead. As soon as the blades are turned to a smaller angle, the lift force is reduced and the forward thrust decreases. The ship speed is thereby reduced, but owing to its forward momentum this does not occur as rapidly as the change of pitch. Consequently, the angle of incidence of the blades is reduced and tends towards the angle of no-lift, the centre of pressure moving rapidly towards the trailing edge. That is to say, the moment due to the hydrodynamic forces becomes negative, and since it will then be additive to the centrifugal turning moment, it will assist the pitch change. Furthermore, although the lift force is decreasing, the lever about the blade turning axis increases rapidly and the resultant negative hydrodynamic turning moment may be considerable.

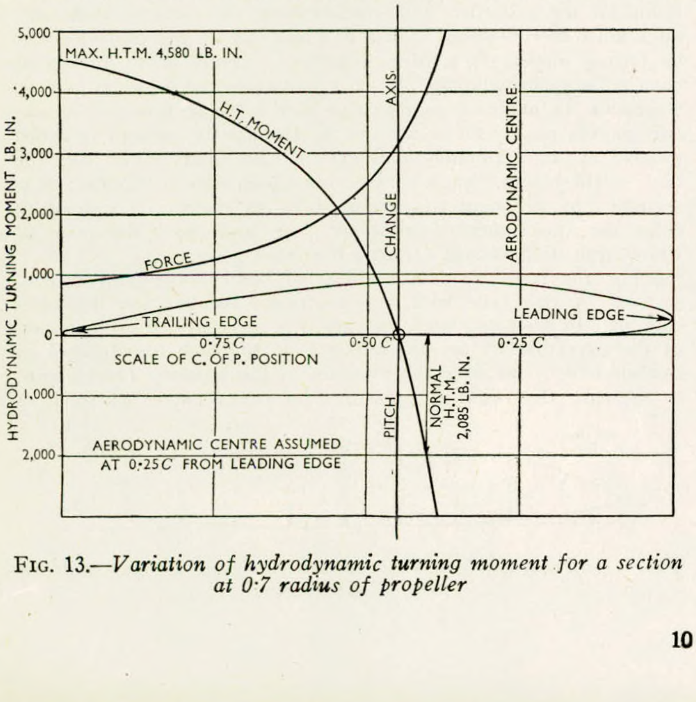

FIG. 13.—*Variation of hydrodynamic turning moment for a section at 0·7 radius of propeller*

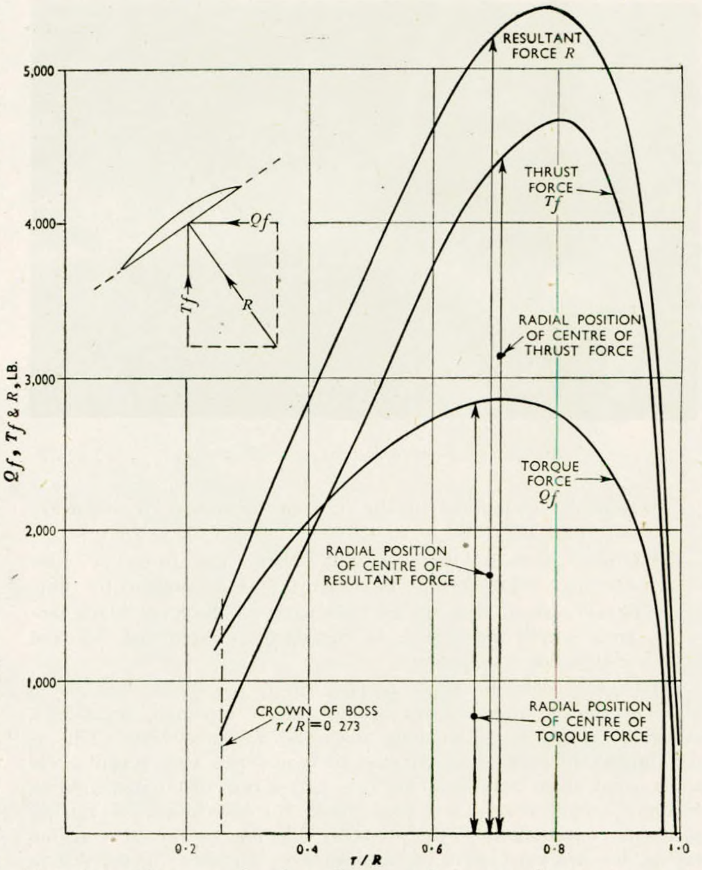

FIG. 14.—*Diagram showing thrust and torque forces per cent length of blade*

Fig. 13, for example, illustrates the variation in hydro-dynamic turning moment for a section at 0·7 radius of a propeller 3 feet in diameter turning at 1,060 r.p.m. as the angle of incidence is reduced to zero. The pitch change axis is in this case 0·45 of the chord from the leading edge and the position of the centre of pressure has been estimated from the expression

$$C_{po}=0{\cdot}25-\frac{C_m \text{ (about } \tfrac{1}{4} \text{ chord)}}{C_L}$$

Furthermore, the value of C_m, the pitching moment about the aerodynamic centre at $\frac{1}{4}$ chord has been assumed to be constant, as the centre of pressure moves towards the trailing edge.

It will be seen that in spite of the rapidly reducing lift force the negative turning moment, as the centre of pressure approaches the trailing edge, increases to a value which is approximately $2\frac{1}{4}$ times that of the initial positive turning moment.

The positive hydrodynamic turning moment on each blade was in this case 2,085lb.-in. so that the negative hydrodynamic turning moment becomes approximately 4,580lb.-in.

In the above, the change in hydrodynamic turning moment for the 0·7 radius section has been taken as typical for the whole blade, which is approximately correct, but for a complete calculation each radius would have to be examined separately, and the resultant couples integrated throughout the length of the blade. In this connexion Fig. 14 shows the radial distribution of thrust and torque forces per unit length of blade, and Fig. 15 shows the levers of the centres of pressure at each radius about the central pitch-change axis for the propeller in question, at the normal ahead blade setting In the case under consideration the value of the maximum hydro-dynamic turning moment estimated from the more

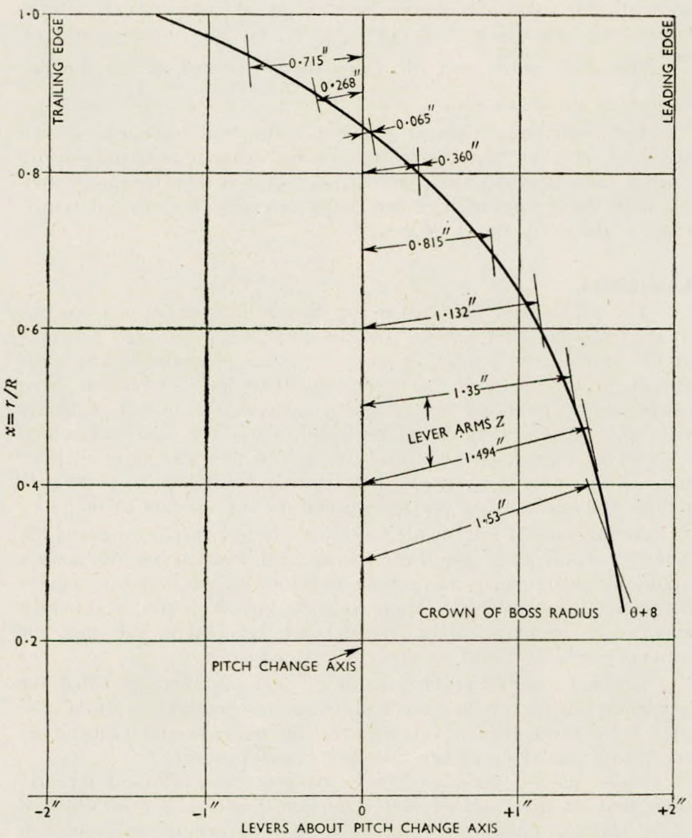

FIG. 15.—*Diagram showing levers of centre of pressure relative to pitch-change axis*

detailed consideration of the actual forces acting on the blade as a whole was 4,670lb.-in., as compared with the approximate figure 4,580in.-lb. given above. As the angle of incidence decreases, the load comes off the engine and there is therefore a tendency to race, and the speed of rotation of the screw may increase slightly, and later, as the angle of incidence becomes slightly negative, the forces acting on the screw may tend to drive the engine momentarily. Finally, as the pitch of the blades becomes negative, the hydrodynamic turning moment is again opposed by the centrifugal turning moment, and the resultant couple on the blade is thereby decreased. As the ship begins to move in the astern direction, the angle of incidence will again pass through a position of no-lift, and there is a possibility of a large turning moment as the centre of pressure moves close to the leading edge in this case. Generally speaking, the centrifugal turning moment is small in relation to the maximum hydro-dynamic turning moment, but with high speeds of rotation the centrifugal turning moment may become of considerable importance.

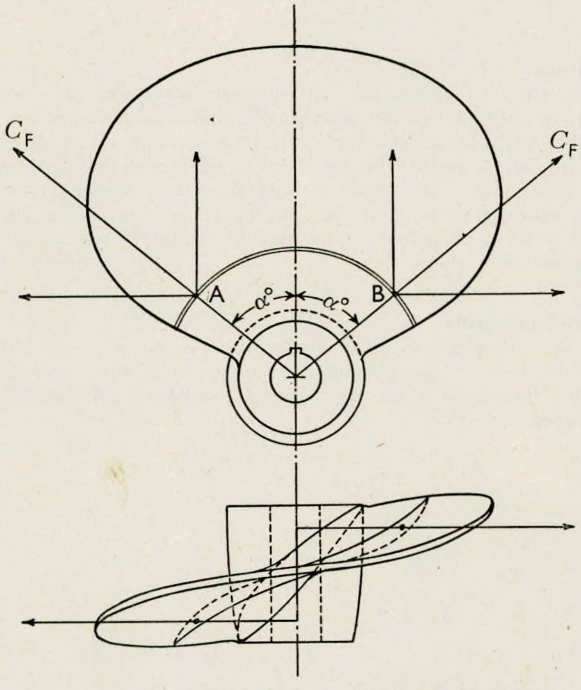

FIG. 16.—*Projected and plan views of a wide-bladed propeller*

Centrifugal Turning Moment

In stressing a fixed-pitch marine propeller, account is usually taken of the direct pull due to centrifugal force, and also of the bending moment which may arise from the fact that the line of action of the resultant centrifugal force on each blade does not pass through the centroid of the root section, but no account is taken of the fact that when rotating at high speed the blades always tend to roll up or twist into a lower pitch. For this reason the concept of centrifugal turning moment is not one with which marine engineers and naval architects are usually familiar, and it is thought that this is worthy of some consideration here. Fig. 16 shows, for convenience, the projected view and plan view of a wide-bladed marine propeller. A and B are particles symmetrically disposed about a vertical line through the shaft axis and situated respectively near the leading edge and near the trailing edge in the pitch face of a section at radius *r*. It is obvious that at any instant the lines of action of the separate centrifugal forces, due to these two particles, will pass through the shaft centreline, the included angle between the two lines of action, as shown in the sketch, being 2α. Furthermore, it is clear that the centrifugal force for each particle may be resolved into two parts, acting upwards and sideways respectively, in the blade position shown, and that the couple tending to bring the particles into a plane at right-angles to the shaft axis is given by

$$(C_F \sin \alpha) \times A\,B \sin \theta$$

where C_F=centrifugal force on each particle

θ=pitch angle of the blade section at radius r.

Examining this question a little more closely, for a segmental section δr thick at radius r (see Fig. 17), it will be seen that for the particle ($\delta x\ \delta y\ \delta r$) shown, the centrifugal moment taken about a pitch change axis, assumed to pass through the mid-point of the face O will be given by

δ (centrifugal turning moment) =

$$\rho\ (\delta x\ \delta y\ \delta r)\ \frac{\Omega^{2} r}{g}\ \sin \alpha\ (x \sin \theta + y \cos \theta)$$

where α may be evaluated from the equation

$$\alpha \text{ (in radians)} = \frac{x \cos \theta - y \sin \theta}{r}$$

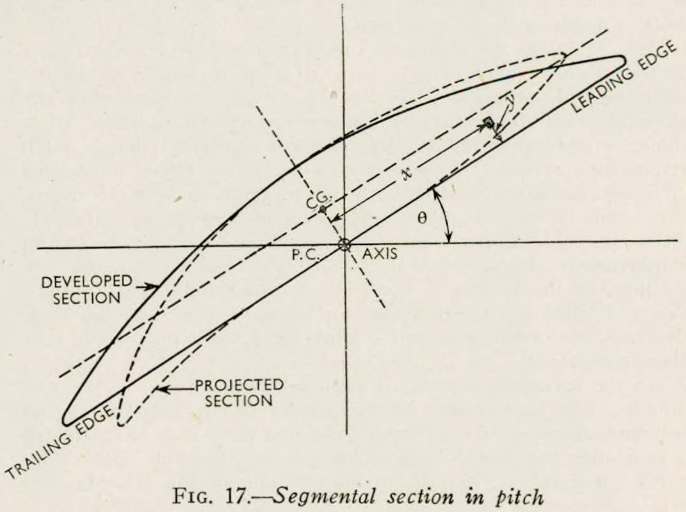

FIG. 17.—*Segmental section in pitch*

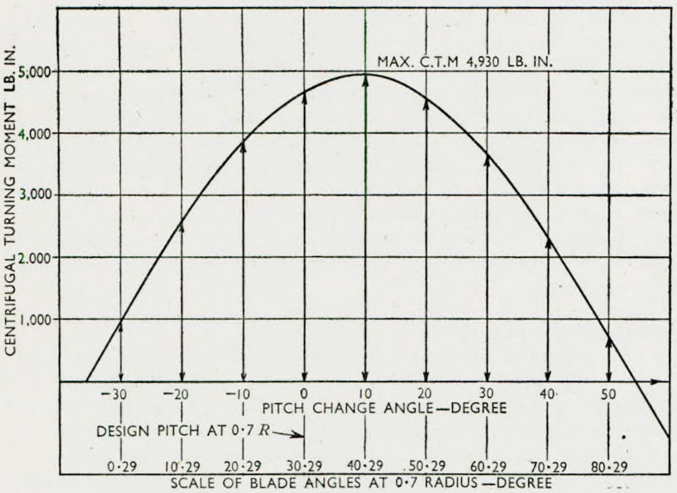

FIG. 18.—*Variation in centrifugal turning moment with blade angle*

If the angle α is small, then $\sin\alpha=\alpha$ in radians, and the resultant expression may be written

δ (centrifugal turning moment)

$$=\rho\,(\delta x\,\delta y\,\delta r)\frac{\Omega 2}{g}(x\cos\theta-y\sin\theta)\,(x\sin\theta+y\cos\theta)$$

$$=\rho\,(\delta x\,\delta y\,\delta r)\frac{\Omega 2}{g}[(x^2-y^2)\sin\theta\cos\theta-xy\,(\sin^2\theta-\cos^2\theta)]$$

Integrating the above expression from the tip radius R of the propeller down to r_0 the radius of the boss total centrifugal turning moment

$$=\rho\frac{\Omega 2}{g}\int_{r_0}^{R}\tfrac{1}{2}\,(I_{yy}-I_{xx}+A\bar{y}^2-A\bar{x}^2)\sin 2\theta\,\overline{dr}$$

$$+\rho\frac{\Omega 2}{g}\int_{r_0}^{R}A\,\bar{x}\,\bar{y}\,\cos 2\theta\,\overline{dr}$$

where I_{yy} and I_{xx} are the moments of inertia of the blade section taken about axes through the centre of gravity for which the co-ordinates are, respectively, $\bar{x}$ and $\bar{y}$, A is the area of the section, and θ is pitch angle at each radius.

Fig. 18 shows the results of such calculations for the propeller mentioned above, plotted to a base of angle measured at the 0·7 radius of the propeller, from which it will be seen that the maximum centrifugal turning moment occurs for a blade angle which is approximately 10 deg. above the normal design pitch setting and reduces to zero for a negative blade setting of −35½ deg. measured relative to the design pitch angle at 0·7 radius. The maximum centrifugal turning moment value is approximately 5,000lb.-in. and is therefore slightly greater than the maximum hydrodynamic turning moment of 4,670lb.-in. mentioned above. In this instance the frictional moment opposing motion was approximately 2,330lb.-in., so that the maximum torque on the blade adjusting mechanism was of the order of 5,000lb.-in. for the condition considered.

In the foregoing analysis it has been assumed that $\sin\alpha=\alpha$ in radians. For wide-bladed marine screws this is not correct, but the appropriate centrifugal turning moment value may be calculated by projecting the helical blade sections on to a plane at right-angles to the pitch-axis, as shown in dotted lines in Fig. 14. In this way all the axial dimensions remain as before, but all lateral dimensions are diminished correctly in the appropriate ratio of $\frac{\sin\alpha}{\alpha}$ for each point, and the calculations proceed as for the developed blade sections.

The centrifugal turning moment value is independent of the speed of advance, but the hydrodynamic turning moment will, of course, vary for each blade setting, so that it is therefore necessary to study these turning moments very carefully for several conditions in the early stages of design.

Lubrication

The problem of lubrication for the pitch changing mechanisms of controllable-pitch screws, and also for the pre-loaded bearings at the base of the blades, is one which has presented many difficulties to the designer. These difficulties have, however, been overcome by charging the hollow spaces in the boss completely with oil, and providing an oil-feed tank above the waterline which ensures a constant positive head of oil. In this way, it is ensured that all the moving parts of the adjusting mechanism, and in particular the bearings of the blades, continually operate in oil.

At the base of each blade, oil seals are provided to prevent the leakage of oil from the hub spaces, and also in recent designs additional water seals have been provided to prevent the ingress of water from outside. There is therefore a double seal which ensures an adequate supply of oil being retained to lubricate the moving parts and also to prevent corrosion.

In the Escher-Wyss design the oil seal is so arranged that the propeller blades can be removed from the bearings without loss of oil from the hub. Consequently the removal and refitting of the blades can if necessary take place under water.

Since the oil pressure inside the boss is continually greater than that of the head of water outside, there is a possibility of some leakage outwards of oil over a long length of time, but experience has shown that this loss is very slight indeed and can be neglected. This oil loss does in fact occur in service, but it amounts to only a few gallons per month.

In some recent controllable-pitch designs water-lubrication, which presents definite advantages for certain types of craft, has been tried out as an alternative to oil-lubrication. It would appear from such reports as the author has had that this system of lubrication is successful, but that there are still some "teething troubles" which will have to be overcome before it can be regarded as a competitor to the more usual oil-lubrication with a constant head.

Conclusion

In the foregoing the author has attempted to discuss, as fairly as possible, the advantages and disadvantages of controllable-pitch propellers for vessels of various types, and also to point out some of the problems confronting the designer of such propellers. The opinions expressed are personal and, no doubt, other opinions may be held by those responsible for the design of such propellers, or by marine engineers who have been associated with them.

Acknowledgements

The author has to acknowledge the assistance of the various manufacturers of controllable-pitch propellers, who have kindly supplied details of their most recent propellers for inclusion in this paper.

Discussion

Major E. C. Hatcher (Visitor) said that the paper was largely devoted to the three better-known types of controllable-pitch propeller, all of which used hydraulic pressure to move the blades, but it might be of interest to mention that there was at least one other type which was mechanically operated, and which had given very satisfactory service over the last two years. Incidentally, it was a water-lubricated propeller. He mentioned this not to compare the merits of one type with the other, but to let it be known that there was such a propeller working. The installation was of about 1,250 h.p. and operated at 480 r.p.m. Another distinctive feature about it was that it did not use a hollow tail-shaft; in fact, the standard propeller shaft was used.

Taking in their order of importance those points in the paper which he thought would be of most concern to engineers and potential users, he would refer first to the question of efficiency. It could not be denied that the larger boss size for a given diameter of propeller which was called for in the design of the controllable-pitch propeller could result in some loss of efficiency. As the author pointed out, these losses had been measured at various times from model experiments. The facts with regard to full-size application, however, were of interest.

Many marine engineers would have read Commander Rupp's paper given before the Society of Marine Engineers and Naval Architects in America on comparable installations on two harbour tugs, one with fixed-pitch and one with controllable-pitch propellers. Summarizing a series of trials, Commander Rupp stated that for all practical purposes it could be concluded that the free route performance of both fixed and controllable-pitch propellers installed in the two tugs was the same, or possibly slightly in favour of the controllable-pitch propeller.

Again, there were the recent trials on the Johnson Line ship *Los Angeles,* one of five similar ships of about 7,200 tons trial displacement—the displacement of the *Los Angeles* being slightly greater. The records of the trials showed that the *Los Angeles,* with the controllable-pitch propeller, for the same horse-power was about ½ knot faster than the sister ships *Seattle* and *Golden Gate,* namely about 21½ knots for the fixed propeller and 22 knots for the controllable-pitch propeller, all three ships absorbing 14,000 h.p. The boss/diameter ratio in both cases was less than 0·30, being 0·26 for the tug and 0·28 for the *Los Angeles.* To his knowledge, satisfactory controllable-pitch propellers had been made with a boss/diameter ratio lower than 0·25.

The author made it clear that a considerable amount of the ill-effect of the large boss could be offset by properly designed cone-nuts and fairing into the propeller, and of the hundred odd Kamewa propellers fitted, most were single screws. The author's proposal that the root widths for blades should extend beyond the circular blade and fit closely round the shape of the boss had been empodied in the design of the propeller to which he himself had referred, and which had been in operation for two years and seemed to be working very satisfactorily, both in that respect and in others.

It was stated in the paper that the time required to perform the operation from full-ahead to full-astern was 60 seconds. Presumably that was not meant to be the minimum time. He referred to this point because those less experienced might form a wrong impression. He knew a number of hydraulically controlled propellers in which this operation could be performed in less than half that time. In one instance he had been prepared to provide for the operation being carried out in 15 seconds, but the time had been extended to 40 seconds to facilitate engine control. In the case of that particular ship, by operating the propellers it was possible to bring the ship from full-ahead to stop in 1 minute 51 seconds. In the case of the American tugs referred to in Commander Rupp's paper, with the fixed-pitch propeller it took 34 seconds and a reach of 402 feet to bring the vessel to zero speed, and with the controllable-pitch propeller it took 26 seconds, with a reach of 303 feet.

The author stated that there should be no difficulty in designing propellers of controllable-pitch type for powers of the order of 10,000 to 12,000 s.h.p. In fact designs were in progress for Kamewa propellers considerably in excess of those powers.

In the second part of the paper, the author listed the advantages and disadvantages of controllable-pitch propeller installations. With regard to paragraph (5) of the advantages, relating to the possibility of avoiding running at or near shafting criticals, once these criticals were established it should be possible to operate a signal or lamp from the governor to give an indication if and when these criticals were reached.

With regard to paragraph (6) of the advantages, it was, he believed, agreed by most engine designers and users that the use of controllable-pitch reversible propellers, avoiding the necessity to reverse the engine, eliminated thermal stresses set up by the introduction of cold air. This must result in less wear and tear and maintenance of Diesel engines.

Paragraph (1) relating to the disadvantages was, he thought, adequately answered by the results obtained with the *Los Angeles.* Paragraph (3) of the disadvantages could be met largely by suitable blade design.

The successful and reliable operation of some hundreds of controllable-pitch propellers, itemized by the author in Table 1, made the suggestion in paragraph (4) of the disadvantages, for the carrying of spare fixed-pitch propellers, verge on the over-cautious. Over 100 Kamewa propellers covering all powers up to 7,000 s.h.p. had been in operation for about fifteen years, performing arduous and onerous duties in tugs and ice breakers without any breakdown to the hub mechanism. So far as paragraph (5) of the disadvantages was concerned, he knew of at least one type of controllable-pitch propeller where the normal shaft-taper and keyways were possible. That was useful if it was necessary to carry a spare fixed-pitch propeller.

With regard to paragraph (6) of the disadvantages, concerning the forces and moments involved in carrying out the necessary pitch alterations when the ship was in motion, which were stated to be high, that point was dealt with on p. 268. All designers of controllable-pitch propellers were cognisant of these forces, and it was a normal design problem to provide the power necessary to carry out the operation. At a rough estimate, the power required was 0·5-1 per cent of the shaft horse-power to move the blades from full-ahead to full-astern in 25-40 seconds.

With regard to paragraph (7) of the disadvantages, experience showed that with a suitably designed cone nut and fairing into the boss the controllable-pitch propeller did not show to disadvantage at free running speed. That was demonstrated by Commander Rupp's paper with regard to the tugs to which he had referred earlier, and the towing advantages shown in that paper were astonishingly high; they ran as high as a percentage gain of about 30 under certain conditions of tow.

In the third part of the paper the author dealt with the application of controllable-pitch propellers to various types of ship. Personally, he himself thought that the advantages of the controllable-pitch propellers for dual purpose ships such as tugs and ice-breakers were fully recognized. One advantage of the controllable-pitch propeller for the submarine which was not mentioned in the paper was that of obtaining a higher ship running speed when charging batteries, or much higher charge for a given speed. Those with experience of submarines would appreciate to the full what those advantages meant.

With reference to merchant ships, no one could deny that it was difficult to make a case for the controllable-pitch propeller working in conjunction with the ordinary reciprocating steam engine, but the advantages of the controllable-pitch propeller for use in merchant ships should be allied with considerations of machinery and the effect thereon. The controllable-pitch propeller would appear to be almost a necessity for the gas turbine. The author had already said that that was the case, and it was unnecessary to reiterate it. Personally, he thought it was possible that a case could also be made for the use of the controllable-pitch propeller in combination with electric drives, particularly in the case of alternating current.

On the question of lubrication, reference was made to a water-lubricated design. His own experience, after two years' successful operation, was that no wear was measurable on any part of the mechanism, and only very little on one or two of the plastic bearings used in the design. The teething troubles with regard to this propeller experienced during the two years concerned only items of control gear; no trouble whatever was experienced with the propeller itself, and the vessel was not out of operational duty for a single day on that account.

Com'r (E) L. Baker, D.S.C., R.N. (ret) (Member) observed that while he was well aware that the author might tell him that the first point he wished to raise was stretching the title of the paper too far, he felt that something should be said about the American Navy trials in the *Dahlgren,* which had as far as he knew the largest horse-power ever used on a single-screw controllable-pitch propeller, namely 14,000. Just before the outbreak of war the Americans were experimenting with this propeller and found considerable loss of power (which they were unable to control). The war then intervened and they reverted to a fixed-pitch propeller.

In the case of the average post-war cargo liner service, the author did not claim that there was any ground for fitting controllable-pitch propellers for the sake of efficiency, and personally he thought that experience would undoubtedly substantiate the view that there was no such ground. Most of those ships were very near their deep marks all the time, and the only use of the controllable pitch would be in bad weather, which was not a high proportion of the time in spite of the Bay of Biscay, and for manœuvring in and out of harbours.

Reference had been made to the carrying of an additional fixed-pitch propeller to deal with the position which would arise if the controllable-pitch propeller broke down. He believed it was correct to say that most current designs for controllable-pitch propellers took account of this by arranging that when the controlling gear broke down the propeller went into the full-ahead position and stayed there. Where that was so, there seemed to be little ground for fitting a fixed-pitched propeller. In neither case were the astern requirements covered.

On the question of the utilization of controllable-pitch propellers with steam turbines the omission of the astern turbines would improve the efficiency about 0·5 or 1 per rent due to the lack of windage. It was necessary to offset against that the loss due to the controllable-pitch propeller, which could be taken as being between 2 and 5 per cent. In the case of gas turbines, he did not think it would be disputed that some form of reversing other than engine reversing was necessary, but a consideration of the turbine characteristic of both steam and gas turbines would show that the turbine condition when utilizing the controllable-pitch propeller resulted in an even greater loss of efficiency than using a fixed-pitch propeller, so that one did not in fact gain in efficiency by using the controllable feature. One was therefore left with the conclusion that if mechanical problems had to be faced one might at least face them where one could control them—inside the ship—and design a suitable reversing gear.

Mr. Arthur F. Evans (Member) said that Priestman devised an excellent reversible propeller many years ago. Personally, he had been worried about the vulnerability of the reversing propeller. In 1900 he himself took out a patent for a reversing propeller, of which quite a number were made. It was very free from trouble as far as the propeller itself was concerned, but there was one grave defect on which he would be interested to hear the author's views: they found it utterly impossible to maintain neutral. He knew that the centrifugal force tended to bring the blades into neutral, but as soon as the propeller moved from neutral the leading edge imparted such a torque that the propeller went either into full-ahead or full-astern, and nothing which they could devise would give sufficient neutral to make it possible to leave the engine running.

He had said that they had no trouble from vulnerability. This had been obviated by the design adopted for the propeller boss, making it quite long and attaching to the stern-post a substantial sleeve which was just a clearance fit with this long boss. This preserved the propeller and the shaft from damage. He continued that arrangement in later years with fixed propellers, extending the propeller boss and putting a faired and very heavy sleeve on the stern-post to take the boss. In the lifeboat service, where the idea was used, it was found possible to jack up a boat weighing 15 tons by the propeller boss without trouble.

With regard to the rapidity of propeller movement, in the case of his own little propellers to which he had referred earlier, the time was more like one-sixth of a second than 60 seconds. With that little propeller, the blade had integral pinions; there were racks, a yoke, and a sleeve which was carried inboard.

He would like to know whether the torsional vibration had any ill-effect on controllable-pitch propellers. He knew that the torsional vibration generated by the propeller was very serious, and he wondered whether the articulated mechanism which had been described would suffer in any way.

One advantage which had been claimed for the controllable-pitch propeller was that it made it possible to run the engine the whole time. He could not see that there was any advantage in that; he thought that the ideal thing was to stop the engine when one had finished with it, and not let it run continuously, hour after hour.

Finally, he had never been quite clear about the effect of distortion of pitch. A propeller was designed for a certain helical plane and then it was distorted, so that the pitch was incorrect. Did that have any appreciable effect?

Mr. R. K. Craig (Chairman of Council) asked the author whether, if he was a superintendent engineer and was going to put a gas turbine into a ship, he would put in a reversible propeller or some form of electrical or mechanical reversing mechanism.

Mr. A. W. Jones (Associate Member) wrote that when considering the suitability of any item of a ship's machinery, the marine engineer should assess very carefully its affect on (a) the efficiency with which the vessel could fulfil its various duties throughout its life, and (b) seaworthiness.

The use of a variable-pitch propeller could affect the efficiency of a vessel in two ways. As the author clearly pointed out, for ships which had to operate for appreciable periods at two or more widely different conditions (such as tugs, tankers and trawlers) an improvement in the fuel consumption could be obtained by using variable-pitch propellers in place of the fixed-pitch type. Secondly, the complication of the reversing mechanism could be removed from the main engine and put in the propeller boss. For steam and gas turbine prime movers, thrust reversal by means of a variable-pitch propeller would probably entail a first cost less than that for any other type of reversing arrangement, whereas in the case of reciprocating machinery first cost considerations would be in favour of the direct reversing main engine. The assessment of the total affect of difference of fuel bill, first cost and maintenance was a matter of judgment in each case. The majority of merchant ships operated most of the time at conditions which, for any given vessel, were not widely variable, so that the saving in the fuel bill to be expected from the use of a variable-pitch propeller on such vessels, was less than in the case of a vessel having widely variable conditions of service.

Seaworthiness was a quality which was difficult to assess financially, and yet a ship should possess it if it was to operate at its maximum efficiency. Of the many factors comprising seaworthiness, one of the most important was the ability to stop within as short a distance as possible. It was therefore essential to obtain maximum reversed thrust as soon as possible after the need arose, and it appeared that this could be more quickly done by means of a reversible propeller than by means of a direct reversing engine. However, there remained considerable scope for further investigation into the stopping of ships by various means of thrust reversal, and it was one in which manufacturers of reversible propellers would be particularly interested as he considered that it was the only selling point worth being considered by a superintendent in charge of a fleet of normal cargo and passenger carriers.

Any item on a ship of such functional importance should be of proved reliability and preferably so positioned that maintenance could be carried out by the engine room staff. The reliability of the variable-pitch propeller could only be demonstrated by continuous successful operation over a number of years and by its very nature, it would have to be accompanied by a direct reversing engine during the proving stage, so that it was only owners who were willing and able to incur the extra expense who could demonstrate its reliability or otherwise. In these days of increasing tonnage and diminishing freights, the opportunities of proving the variable-pitch propeller in ocean service would be fewer. It might pay the manufacturing firms to subsidize one or two pilot installations—such a gesture would help convince marine engineers that there were real advantages to be gained by the use of a reversible propeller.

For ocean going vessels fitted with variable-pitch propellers, he felt strongly that normal manœuvres should be carried out by the engine room staff with an emergency crash reversal mechanism available on the bridge. The reversal of thrust was not the only change required while manœuvring a ship, but it was the only operation which lent itself to remote control. All the control of boilers and auxiliaries which was necessary for matching with the main engine should be carried out by engine room staff and this could only be done efficiently if the control of the main engine was also in the hands of the same men.

Mr. R. F. Linsell (Member) wrote that electrical engineers would welcome this paper as it gave hopeful signs of the advent of constant-speed propellers. These could simplify the electrical engineer's task appreciably if used in conjunction with a constant frequency alternating current drive.

The combination belonged to the future, and would probably not be used until a satisfactorw a.c. winch had been produced, but it was interesting to note that the Germans built a ship in 1938 in which two turbo-alternators supplied power to two 2,000 s.h.p. Voith-Schneider propellers and all ships auxiliaries. This arrangement became more attractive, the greater the ratio of auxiliary to propulsion power, and the larger the harbour load.

It might be very convenient, in the teething stages, to use a.c. drive with a variable-pitch propeller when developing the marine gas turbine. Auxiliary Diesel engines could then provide a source of stand-by power for propulsion.*

The problems to be solved before constant frequency a.c. drive could be used commercially were:—

(1) Development of standard lines of marine type a.c. motors and starters.
(2) Development of marine type air-break switchgear.
(3) Development of an a.c. winch.

Of these, only (3) was a technical problem, and there were already some solutions available. (1) and (2) would solve themselves when manufacturers were able to devote the necessary time and thought to the matter and were given sufficient inducement.

The electrical engineer would require some information about the control requirements of a constant speed variable-pitch propeller. Could they be started up slowly from the engine-room and then left in neutral while the ship was still alongside or would there be a request for push button control from the bridge? The former could be done easily but the latter would require extra control gear.

Mr. J. H. Trickey (Member) wrote that his firm had been following the progress of the controllable-pitch propeller for a considerable time and had actually manufactured small ones for engines up to 80 b.h.p. These were used mainly for fishing boats which carried out line fishing from Newlyn and adjacent Cornish ports. The advantage was absolute and immediate control of the boat's speed with a constant speed engine by altering the pitch of the propeller which was controlled by the helmsman in the deck house, where the fishing operators were under his supervision.

With reference to lubrication they favoured the water lubricated type and he recently had the opportunity to inspect two propellers of this type which had operated for 25,000 miles and the condition of the plastic bearings was excellent.

The main problems for the controllable-pitch propeller manufacture as he saw it were:—

(1) Vulnerability, making propeller guards advisable.
(2) Accessibility to operating mechanism when the vessel was afloat.
(3) More rapid operation from ahead to astern at service speed.

In conclusion he would say that the application of the controllable pitch-propeller in connexion with the gas turbine would seem to give the former an assured future.

Mr. G. S. Selman (Member) wrote that is must be admitted that the mechanical design of the propellers described was sound and proved by long experience. It should, however, also be freely admitted that the large boss required to house sufficiently lightly loaded mechanisms—approximately 30 per cent propeller diameter—did detract from the maximum working efficiency. He would assess this as a loss of from 4 to 6 per cent. The variable-pitch propeller did not appeal as a possible improvement of propulsive efficiency in a ship, but might reduce the fuel used at lower powers in the case of engines with a poor fuel characteristic; particularly was this the case with gas turbines. Their use would improve the flexibility of Diesel engines normally incapable of running steadily below 30 per cent of the maximum r.p.m.

At one time he compared a variable-pitch propeller installation with the normal reverse gear fitted to high performance motor torpedo boats, and found little to enthuse about. The cost was double, the weight 5 per cent greater, and since the engine had an exceptionally good fuel characteristic, adjustment of pitch, except at very very low speeds, showed but a few per cent increase in range.

If the advantages claimed could be obtained in any other way, then he thought the vogue of the variable-pitch propeller would be short lived because of the very high cost of replacement.

It was probable that very soon—many designs had already been prepared—there would be available magnetic reverse gears, which, while having most of the advantages of variable-pitch propellers, had the added advantages of separation of propeller drive from engine, and hence reduction of damage to propeller if fouled. Such a reverse gear could fulfil the author's claims (1) to (6) and the propeller could give a better performance at full speed.

He saw little need to design a tug propeller for other than its towing condition. If this was done in the case of a Diesel tug, very little speed was lost when free running at the maximum r.p.m., the form was then being overdriven, and the loss of speed of no importance.

It was surely in the case of ice-breakers unwise to expose such an expensive mechanism to the hazards of damage from ice, here the break in transmission provided by a magnetic clutch would be invaluable.

With regard to the M.T.B. propellers he was sorry that the author had mentioned boost pressures which were the fetish of engineers brought up on steam, and used to de-rating engines designed to give much higher power than allowed by the authorities. A similar engine to the one mentioned by the author, but not supercharged, was used successfully for years, particularly for towing high-speed tagets, when the r.p.m. was reduced by increase of load from 2,400 to 2,000. At the end of the war, induction pressure gauges were introduced with the same unfortunate consequences. The primary influence on the hump in the power curve of such fast craft was load, which increased its definition at speed length ratio of 3·0. With the introduction of the gas turbine, the variable-pitch propeller would be a necessity, at least at the present time; progress along the lines favoured by Ricardo might so improve the fuel characteristics, that even here a reverse gear of the type indicated might find favour. In no type of craft were the propellers so vulnerable as this.

Fishing craft did not normally trawl at anywhere near top speed, and there existed such a margin of mean effective pressure at lower speeds, that it was not possible to overload the propeller. Maximum top speed was, however, an economic necessity, and this the variable-pitch propeller could not give.

For inland water transport, which were normally propelled by high-speed Diesel engines incapable of running normally at all steadily below 30 per cent r.p.m., the variable-pitch propeller would

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* Linsell, R. F., 1948, Trans.I.Mar.E., Vol. 60, p. 167, "Electric Power for Ships".

offer advantages over type, but here again the power to vary slip would make the magnetic clutch reversing gear a rival.

If the variable-pitch propeller found favour he imagined that Diesel engine manufacturers would be greatly concerned to prevent the overloading of their engines by injudicious increase of pitch.

The case of cargo boats quoted by the author whereby the r.p.m. of an engine were dropped from 102 to 86, would surely overload the engine by 15 per cent (5 per cent above B.S.I.) if the propeller was correctly designed to absorb 10 per cent less power than B.S.I. at its service speed.

In effect, having first dropped the ship's speed from 13 to 12 knots and so secured a margin of 16 per cent, the r.p.m. were then reduced by increase in propeller pitch to re-absorb the margin. If the propeller had been designed for its service speed and maximum continuous b.h.p., this manipulation would not have been possible.

Little data had been published by manufacturers of variable-pitch propellers to indicate that the problem of correct balance had been successfully solved. Bearing in mind the troubles still experienced with ships' rudders, such data would be both informative and reassuring. He had little doubt that the splendidly equipped hydraulic laboratory of Escher Wyss had completely explored the problems presented, and that the variable-pitch propeller introduced in the days of Dr. Ackeret would have been both mechanically and hydro-dynamically perfect.

One further remark concerning high-speed Diesel engines; their propellers normally had very low pitch ratios, and since the peak efficiencies of smaller pitch ratios so quickly approached zero, this fact must seriously affect the use of a variable-pitch propeller for such classes of ships as tugs, river craft and trawlers, and the like in favour of the alternative slipping clutch.

Mr. G. A. Burkhard (Visitor) wrote that concerning the hydrodynamic question of the controllable-pitch propeller the author directed attention to the influence of the large boss diameter on the screw efficiency. This influence formed indeed, an important problem of controllable-pitch propeller design.

From his own experience, gathered in the cavitation tunnel of the Escher Wyss Works at Zurich and by experiments in the Wageningen tank, it seemed necessary to regard this influence of the boss diameter in dependency on the size, power and speed of the screw in question.

For large, slow turning controllable-pitch propellers, with a hub diameter of 25 to 30 percent they found that the loss of efficiency through the larger boss was insignificant, if the thrust distribution was chosen with a view to minimizing the swirl core behind the hub; especially for single-screw vessels, where the rudder or the stern frame reduced the influence of the boss drag.

For fast twin-screw vessels, with high powered and high-speed propellers, however, the disadvantage of the larger boss could become more important.

In addition to the four causes, which were mentioned by the author for a possible loss of thrust and efficiency, frictional resistance of the hub itself might also have to be taken into consideration.

Whereas this resistance absorbed about 0·10 to 0·25 per cent of the shaft output of a large slowly turning controllable-pitch propeller for a merchant vessel, this loss could increase to one per cent or more for a high-speed craft, with high-powered controllable-pitch propellers with a boss diameter of 30 to 35 per cent and a high rotational speed.

On the other hand, the loss of working blade surface due to the shorter blades, was not very injurious to the performance of the controllable-pitch propeller, because it would be cut off a part from the surface on the root of the blade, where it produced thrust generally with a very low efficiency. Calculations and experiments had shown also that a screw with a larger boss needed a small total blade surface than another one with a smaller hub, if both of them were designed for the same working conditions and cavitation number.

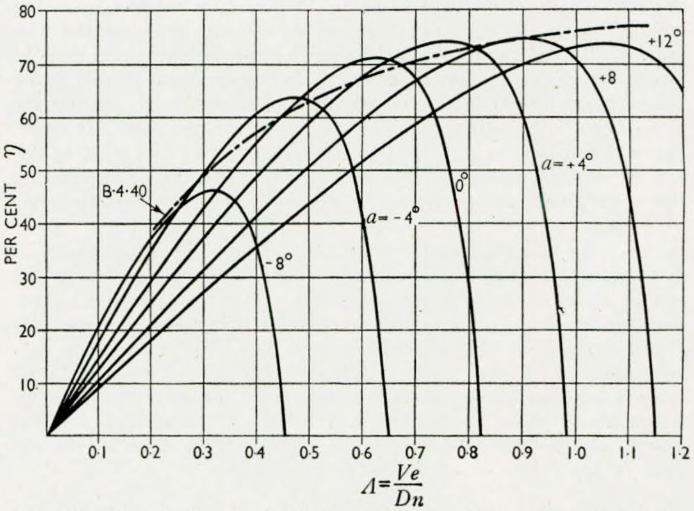

FIG. 19.—*Comparison of efficiency curves for controllable-pitch propeller at various blade settings with standard B.4.40 screw*

When taking all these influences into consideration, the losses in efficiency of a high-speed controllable-pitch propeller compared with a usual fixed-pitch screw, both of good design, might be about 2 or 3 per cent. They were, thus, approximately of the same value or still smaller than the losses caused by the astern stages of a steam turbine.

The author was right with his observation that the most favourable efficiency of a controllable-pitch screw could be only attained for one certain position of the blades. But the decrease in efficiency by changing the blade angle was not important in a space of several degrees, as shown in Fig. 19. The comparison of the efficiency curves of a controllable-pitch propeller for a number of different blade angles, with the dotted curve of the efficiencies of the Wageningen series B.4.40 showed a certain superiority of the first one for the blade angles between −6 deg. and +8 deg. Not before greater deviations from the design posi-

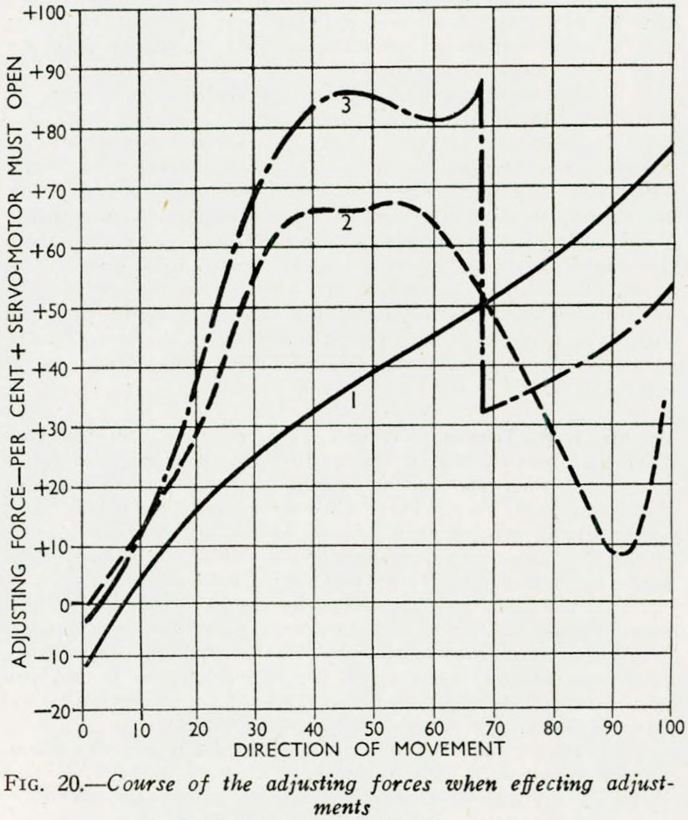

FIG. 20.—*Course of the adjusting forces when effecting adjustments*

1. Quick even movement in max. 1 sec.
2. Slow even movement in max. 22 sec.
3. Irregular movement in max. 16 sec.

tion, did the controllable-pitch propeller's efficiency become smaller than that of the standard series.

Furthermore, the blade position had an important influence on the cavitation effect. If the blades were turned open (i.e., the pitch was greater than designed), the cavitation on the outer part of the suction side would be increased. If they were turned closed, there was more chance of root cavitation.

The design position of the blades was to be chosen in consideration of all these facts and generally it would not always be the full-speed position of the screw.

Concerning the problem of adjusting forces, detailed tests with an Escher Wyss propeller were made some years ago.

Figs. 20 and 21 showed the results of these experiments.

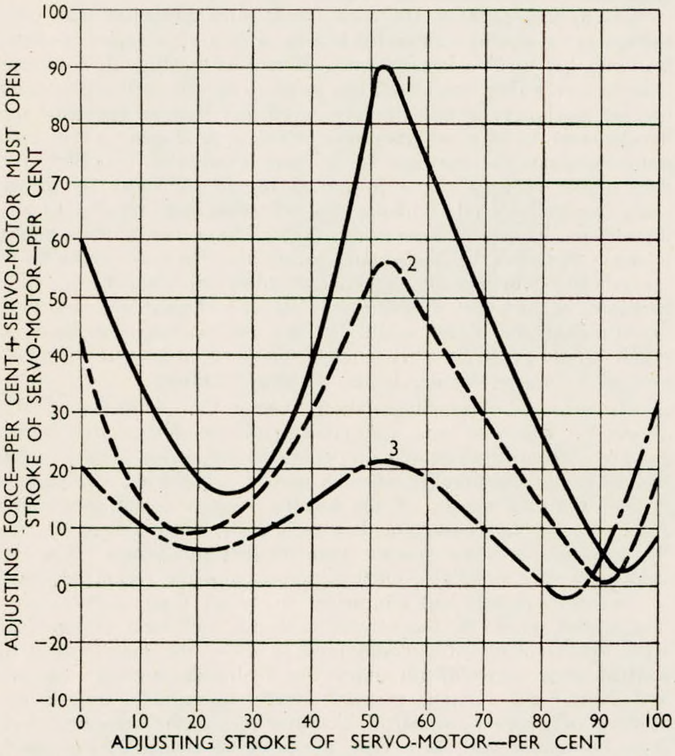

FIG. 21.—*Course of the adjusting forces under uniform working conditions*

1. Speed = 450 r.p.m.
2. Speed = 350 r.p.m.
3. Speed = 250 r.p.m.

The resulting turning moment was nearly always negative (i.e., it tended to turn the blades into the astern position).

Regarding finally the utilization of controllable-pitch propellers for several types of vessels, the advantages offered by this kind of screw for turbine driven ships should be noted.

The elimination of the astern stages made it possible to lessen the distance between the turbine bearings and thereby to build machines with a higher rotational speed. A gain in size and weight would be the result.

Furthermore a constant direction of rotation permitted the building of turbines for higher live steam pressures and temperatures than was now usual, which would have a more economical steam consumption and permit the driving of auxiliaries with extraction steam from the prime mover.

Finally, quick reversing of the propeller and an astern power of 100 per cent of the ahead output gave faster stopping and better manœuvrability of the vessel.

Mr. D. E. J. Offord, M.I.N.A. (Visitor) wrote that if a reversible propeller was required for hydro-dynamic or machinery operating reasons, he was confident that the mechanical problems involved could, and would be, solved. But they were considerable, especially at larger powers, and this appeared to be yet another example of shipborne equipment for which nothing much short of 100 per cent reliability could be accepted. Bench or basin trials would not serve to trace all the little breakdowns which could occur under seagoing conditions. Only extended use could ensure that a design was immune from failure, or even partial failure, under the impact and rough usage conditions which would occur at sea in bad weather. It would seem, therefore, that those operators interested in variable-pitch propellers should, at a very early stage, have some representative designs undergoing comparative and protracted tests under seagoing conditions. If variable-pitch propellers were fitted in warships, it was desirable that they should be no more vulnerable to damage by enemy action than the present types.

Mr. L. G. Stevens, M.I.N.A. (Visitor) wrote that it would be well to remember at the outset that propellers with a capacity to make changes in ahead pitch through a small range would satisfy most requirements where propulsive performance depended on obtaining a favourable combination of several factors. Manufacturers so far had provided a complete pitch range from full ahead to full astern, and had thereby brought about other changes in machinery arrangements which required careful investigation of the resulting overall balance of advantage.

Set down in the broadest possible terms, controllable-pitch propellers enabled the speed-r.p.m. relationship to be altered in the interests of overall effectiveness and, or alternatively the efficiency of the engine-propeller combination. As the author showed, the controllable-pitch propeller began with the efficiency balance fairly heavily loaded against it. In very many cases alteration of pitch to increase engine economy or output would result in the propeller working at a less favourable slip and therefore reduce efficiency and this possibility should be added to the other sources of efficiency loss which the author enumerated. It was of interest in this connexion that the author stated "loss in efficiency due to the increased boss diameter had been fully appreciated by the designers of controllable-pitch propellers". It had not been his own experience that this had been by any means generally admitted and it was well that this should be underlined. The loss on this account might in some cases prove decisive when considering whether to adopt such propellers and no effort should be spared in reducing the boss diameter to the minimum which reliability in service allowed.

Referring to the first advantage claimed for controllable-pitch propellers, control from the bridge, without reference to the engine room, might not be an unmixed blessing unless very reliable automatic engine controls were included.

Of the disadvantages mentioned by the author the effect of high stresses in the blades and blade-operating mechanisms on reliability and maintenance were obviously matters of the greatest importance in warships. Vulnerability of the blade-operating mechanism would also be a matter of serious concern.

It should be remarked that cavitation under full speed conditions was only one of the factors relevant to the case of M.T.B.'s. The character of the resistance curve due to planing and the relatively large range of displacement conditions in these craft was even more important. Indeed, as a result of cavitation the load on the engine was often more nearly balanced between cruising and full speed conditions that it would otherwise be.

With reference to submarines the author appeared to have overlooked the fact that the propelling machinery for surface and submerged propulsion was generally different and it followed by no means necessarily that controllable-pitch propellers would enable the dual requirement to be met more advantageously. With a Schnorkel arrangement as adopted in some German designs the use of controllable-pitch propellers might well be advantageous.

He fully endorsed the author's remark that where the efficiency of a controllable-pitch propeller had in fact been raised to that of a conventional design of similar dimensions, the latter should be capable of improvement.

The Author's Reply to the Discussion

Professor L. C. Burrill in reply wrote that since the discussion represented the views of marine engineers and naval architects, engine designers and propeller designers, he did not think it would be proper to attempt to answer all the questions raised, but he would endeavour to summarize the main trend of the discussion, and would also reply to some of the contributors in the light of his own experience.

He did not feel that there had been any marked disagreement with the main views which he expressed in the paper, but many of the points which he made had been amplified considerably and had been subjected to some criticism in detail. For example, he believed there was general agreement that controllable-pitch propellers were now accepted as being efficient from the mechanical point of view, although some contributors still expressed doubts as to their vulnerability to damage in service, and the relative advantages of oil and water lubrication were the subject of some debate. There seemed no doubt that controllable-pitch screws were a valuable development for dual purpose craft, and that the extreme manœuvrability which the controllable-pitch drive made possible was generally regarded with favour. Some contributors had very appropriately stressed the advantages in fuel saving which could be derived from the proper use of sush screws with certain types of engines under conditions where the full power was not required, and the elimination of astern turbines and gears was considered by others to be a distinct advantage. So far as the gas-turbine was concerned, the controllable-pitch propeller was regarded as being a very satisfactory solution of the problems both of astern running and also of the efficient running and control of the turbine in the ahead condition.

It was generally agreed, by the majority of contributors, that the larger boss of the controllable-pitch propeller led to some initial loss in efficiency when compared with a good fixed-pitch screw, but the amount of such loss was the subject of some debate. It would appear to vary between 2 to 3 per cent and 5 to 6 per cent according to different estimates, and generally speaking the higher figures appeared to be put forward by propeller designers who had had experience with built-propellers. Perhaps the best conclusion to be drawn from the discussion was that this loss could be reduced to about 3 per cent with careful design of the inner sections and proper streamlining of the boss shape and appendages.

Referring to Mr. Hatcher's comments, the examples quoted in the paper referred to the three main types of hydraulically operated screws which had been in service for some time. There were, of course, other types which had been introduced in the last few years and it was interesting to note that one of these was of the mechanically operated type which did not require a hollow shaft and used the normal shaft taper and keyway. It was also interesting that the water lubricated system had proved successful over a period of about two years. It would certainly be advantageous to reduce the boss-diameter ratio to less than 0·25, and any system which would consistently make this possible would be highly desirable. The photograph and other details given in the paper were for the *Los Angeles* propeller. It was correct that this vessel obtained a slightly more favourable result on trial, but this was believed to have been due to the ability to obtain a more favourable power-revolution correlation in the trial condition of the ship, which would not obtain in the fully loaded condition. In order to be quite fair in assessing the results given in Commander Rupp's paper, it should be pointed out that the tug propellers he discussed were of quite different types. The fixed-pitch propeller with which the comparison was made was a very poor propeller, and not one which would have been proposed for efficient free running. The controllable-pitch screw had streamline sections, and was intrinsically a better design. There was, of course, no doubt regarding the improved performance of the controllable-pitch screw under towing conditions but a better result could have been obtained when running at full speed with a good aerofoil-type propeller. The necessity for a lamp-signal to indicate when critical revolutions were passed through was not entirely advantageous, and deck-officers would not easily control the revolutions in all conditions without reference to the engine-room staff under such circumstances.

Referring to Commander Baker, the paper by Commander Rupp was published after the present paper was completed. It was not therefore possible to deal with the material which it contained concerning recent developments in America. There seemed no doubt from the information available in this country that the American Navy conducted extensive trials before the war with vessels of various types and that the conclusion then reached was that the operational advantages to be obtained on large vessels were negligible. In some instances difficulty was experienced with the operating mechanism. Since the war, experience with later controllable-pitch screws had been much more favourable, and better results had been obtained.

As in this country, the controllable-pitch propeller was considered to be worthy of careful testing with a view to its eventual use with gas-turbine installations. It was interesting to note that Commander Baker considered the gains to be obtained with steam turbine machinery would be very small and that he favoured the development of a new type of internal reverse-gear. His own remarks about the carriage of a spare fixed-pitch propeller for long ocean voyages, were prompted by the difficulty of fitting spare controllable-pitch blades and carrying out repairs to the internal mechanism in foreign dry-docks where the facilities might in some instances be inadequate, rather than by any doubt as to the efficient working of the controllable-pitch mechanism. For example, in the event of collision with an underwater obstruction, or stranding, the blades might be bent and the simplest form of repair would be to fit a fixed-pitch screw to enable the vessel to proceed to a port having better docking facilities.

It was very interesting indeed to have the comments of Mr. Evans, as one who was associated with the design and manufacture of controllable-pitch propellers in the period between 1900 and 1907 when a number of such screws were tried. It seemed evident that the theory of the turning moments and controlling forces on the blades was not then fully understood, and it was for this reason that some screws were difficult to operate. The development of controllable-pitch airscrews and the recent advances in propeller theory had eliminated many of these uncertainties. There was no doubt the use of a simple rack and pinion gear with low velocity ratio would tend to make the maintenance of neutral pitch very difficult unless the hydraulic turning moments and centrifugal turning moments were favourable, and in the absence of proper theoretical examination of the various conditions this could only have been a matter of chance in the choice of blade shape, etc. In the case of the small lake vessel mentioned, the ship was continually in operation on Lake Zurich and there was a definite advantage in allowing the engines to turn constantly at fixed revolutions in one direction. The movements of the ship were controlled entirely from the bridge, and no doubt the engine would be stopped if the vessel were to remain for any length of time alongside the landing quay.

In asking the straightforward question as to whether he would prefer to use a controllable-pitch propeller or the electric drive or mechanical gear change in conjunction with a gas turbine, Mr. Craig represented very adequately the position of the marine superintendent at the present time. Dr. T. W. F. Brown, in his recent Parsons Memorial Lecture, had stated that it was their intention to develop a large hydraulic reversing gear. This represented the view of one very competent authority and there seemed no doubt such a gear would be welcomed by marine engineers. The reversing gear shown by Dr. Brown appeared to be a very large and rather complicated mechanism, and his view was that at the present time the controllable-pitch propeller was the simplest solution to this problem of reversing the gas turbine. Undoubtedly, engineers were working hard on the problem of producing a satisfactory reversing gear for such engines and a simple idea for such a mechanism might emerge at any time, but the development of large-scale Kaplan turbine runners, such as were illustrated in Fig. 8 would appear to have given the controllable-pitch propeller a definite lead in this connexion.

He agreed with Mr. Jones that the fuel saving on tugs and other dual purpose vessels would be favourable, but at the present time there had been no considerable body of experience with the controllable-pitch propeller on merchant ships, and it was interesting to have Mr. Jones's confirmation that in his view the fuel saving would be small for such applications. Mr. Jones's suggestion that the use of a direct reversing engine in conjunction with the controllable-pitch propeller was necessary in the initial stages was one which would have to be considered by the classification societies for each proposed application, but it appeared to himself that this restriction would make the development of a satisfactory installation unduly slow, and in view of the successful operation of controllable-pitch propellers already fitted, it appeared that this extreme requirement coud be relaxed in certain instances. Mr. Jones's suggestion that the reversal of the propeller should be controlled from the engine room rather than from the bridge would appeal to many marine engineers, and it seemed clear that this arrangement, if it could be adopted, would enable the engine-room staff to adjust the engine settings, if necessary, at the same time as the propeller is reversed.

Referring to Mr. Linsell, it had been understood for some time that the use of a controllable-pitch propeller would assist in the development of new electric drive arrangements, and it was very valuable to have had Mr. Linsell's comment that the use of a constant speed of rotation at the propeller would be very favourable if used in conjunction with a constant frequency alternating current drive. It was interesting to note that the development of such a drive was attendant upon the production of a satisfactory a.c. winch and that this problem was at the present time being tackled by the manufacturers. It would appear that Mr. Linsell would also favour the control of the controllable-pitch mechanism from the engine room. The experience of Mr. Trickey with small fishing craft with a constant speed engine appeared to confirm the advantages reported by Swedish owners, but the problem was rather different in the larger fishing craft, where the desire for the free-running condition was the controlling factor. Those controllable- pitch propellers which had a large part of the mechanism fitted at the inboard end of the shafting would be favourable from the point of accessibility of the mechanism when afloat.

In referring to the boost pressures as being the limiting factor in connexion with M.T.B. installations, he was using the criterion adopted during the war in judging the performance of high-speed engines. It might be better to express the limitations of such engines in terms of propeller torque, but the overall conclusions would be the same. Mr. Selman was quite correct in drawing attention to the high vulnerability of M.T.B. propellers, as the replacement rate for such propellers under war conditions was very high indeed, and this factor must be taken into account in considering the use of controllable-pitch propellers for such craft. Mr. Selman appeared to consider that the use of a magnetic type of reverse gear would be most favourable in conjunction with high-speed Diesel engines, and it was interesting to note that this matter was being examined by manufacturers at the present time. The service speed of the vessel considered in his earlier paper was 13 knots, and as the propeller was designed for this condition there was no gain for the controllable-pitch propeller at this speed. It was therefore necessary to examine the possible advantages to be derived from such an installation at lower speeds, and for this reason both the 12-knot and 10-knot condition were considered in good weather. The 12-knot speed was also considered for the heavy weather condition as the increase in e.h.p. would limit the speed of the vessel in heavy weather.

Mr. Burkhard had had much more experience with the design of controllable-pitch propellers than he had himself, and the remarks made on the comparative loss in efficiency to be expected in the case of large slow-turning propellers and fast twin-screw propellers were therefore very valuable. Mr. Burkhard very rightly drew attention to the friction losses due to the large boss at high speeds of rotation. It was correct to state that the loss in efficiency at the propeller would have to be considered in relation to the corresponding loss in efficiency due to the astern stages of turbine machinery and that these would tend to balance each other. It was interesting to note that higher turbine speeds and higher steam pressures and temperatures would be possible in conjunction with a controllable-pitch propeller. The discussion of the blade turning moments in the paper was entirely theoretical and the diagrams included in the discussion by Mr. Burkhard, showing the measured turning moments, were therefore a very valuable addition to the information given in the paper.

It was interesting to note that Mr. Stevens, who had experimented with controllable-pitch propellers, considered that the loss due to the large boss could be material in some instances, and that this point had not been fully appreciated by some designers in the past. He was quite correct in suggesting that a dual pitch arrangement, which would provide a very limited pitch change, would most likely be sufficient for some applications, and it was possible that if this arrangement was accepted, the boss dimensions could be reduced. In conjunction with Mr. Offord, Mr. Stevens drew attention to the great importance of reliability and vulnerability in the case of warships. It was quite correct that the incidence of cavitation in the case of M.T.B. propellers was frequently favourable in balancing the torque conditions as between cruising and full speed conditions.

MINUTES OF PROCEEDINGS OF THE ORDINARY MEETING HELD AT THE INSTITUTE JOINTLY WITH THE INSTITUTION OF NAVAL ARCHITECTS ON THE 14TH DECEMBER 1948

An ordinary meeting was held at the Institute jointly with The Institution of Naval Architects on Tuesday, 14th December 1948 at 5.30 p.m. R. K. Craig (Chairman of the Council) was in the Chair.

A paper, entitled "Latest Developments in Reversible Propellers" (published in this issue of the TRANSACTIONS) by Professor L. C. Burrill, M.Sc., Ph.D. (Member) was read and discussed. Sixty-two members and visitors were present and four speakers took part in the discussion.

On the motion of L. Woollard (representing The Institution of Naval Architects) a vote of thanks was accorded to the author for his paper.

The meeting terminated at 7.30 p.m.

Metallizing in Relation to Marine Engineering

The paper and discussion were published in Vol. LX, No. 12

The Author's Reply to the Discussion

Mr. J. Barrington Stiles, in reply, said that Mr. Rivett's contribution did not call for any reply. It was a very happy contribution, and he was glad to have support from such a quarter and to learn of his fortunate experiences with sprayed metal from the point of view of resistance to corrosion in, what they must all agree, were strenuous circumstances.

Mr. Clark had asked whether the classification societies agreed that metal spraying could be used. In this country a good deal of building-up work on ships had been done, of course, with approval, but it was left to the discretion of the local surveyor to decide whether metal spraying should be used in a particular instance. Many building-up permanent repairs and some temporary repairs had been done. In one instance Lloyds Register agreed to the repair of a cracked Diesel block by means of spraying the area heavily all over. All that could be said was that Lloyds Register left the matter to the discretion of their local surveyors. For that reason, he would say that in different areas decisions as to what might be sprayed varied a great deal, and this would of course apply to crankshafts and tail-end shafts.

Mr. West had mentioned the plastic condition of the metal particles at the time of impact. One should imagine a sphere of metal which had been externally chilled, though not to any great depth, but to such an extent that the particles had a more or less solid crust. In some cases the actual centre of the particle would be molten and in general the centre would be at about the melting temperature. On impact the crust would collapse and would furnish the effect which gave rise to mechanical bonding both to the parent metal and between adjacent particles.

Mr. West had also referred to divergent views on the process, and he thought that Mr. Logan had made a similar remark. It was true that there were such divergent views. At a recent meeting of a sister Institute, in a discussion involving metal spraying, one member had said, "I do not think spraying metals is good for anything except painting". That was a drastic angle from which to view the subject. But within its limitations metal spraying was excellent for certain classes of work. He might have enlarged on this by mentioning the things which could not be done by metal spraying. For instance with metal spraying one could not join parts together in the same way as by welding. The substance of most criticism was that metal spraying relied on a mechanical bond, and except in a few special cases, this was true, although irrational, since it took no account of the strength of mechanical bonds. Few people took the trouble to consider the value of something that happened to "look wrong" to them—so it came about that the idea of blowing-on metal coatings, being so apparently vulnerable, became the target of much loose criticism. The critics had been answered by the success of work. Mr. West had summed up the position when he said that the process was satisfactory within limitations and that it still depended on the person responsible for carrying it out. One could not just blow metal on to a ship's machinery and hope that it would stay there. But with proper mechanical preparation by any of the processes mentioned in the paper as appropriate to a particular class of work and the proper technique carried out during spraying, the part would certainly not fail as a result of the breaking down of the bond, or by lack of cohesion of the particles.

The value of electro-deposition and of metal spraying had been compared by Mr. Oswald and it was rightly said that each had its own field and that there was not much overlapping. Personally, he thought extremely highly of electro-deposition, but, again, this too depended to a very great extent upon the operator who carried it out. Mr. Oswald represented a company which had specialized on the engineering side of electro-deposition, and he would not like to cross swords with him as to relative merits. There were instances where metal spraying was, and equally where it was not, preferred.

As far as re-metallizing a metal-sprayed job was concerned, it was generally recommended that the original coating be removed by turning or grinding. Interrupted surfaces could certainly be sprayed and he drew Mr. Oswald's attention to Fig. 14 showing a shaft having two keyways at right angles in each end, and the method of dealing with keyways was described in the last paragraph of p. 245.

Mr. Ireland had asked about boilers. A good deal of work connected with the prevention of heat oxidization in boilers was carried out by metal spraying. The air cones of oil-fired boilers, where aluminium was the metal used for spraying was an example. On coal-burning boilers some work had been done in the way of protection of the firebars with sprayed aluminium. As far as the internal protection of the boilers was concerned he did not know of any corrosion work carried out on them, but he did know of instances of external work on boilers in which there had been severe local corrosion. While they were considering boiler coatings to resist heat-corrosion, he might mention that spraying nickel-chromium on steel followed by aluminium and then heat testing to absorb the aluminium through the nickel chromium, had been successfully applied to some parts and had given excellent results. In some cases resistance to heat oxidization had been increased to such an extent that considerable savings had been effected.

Mr. Logan had asked what he meant by the expression "varying circumstances" when referring to conditions at the instant of impact of the particle on the prepared base. He was afraid that he had been rather vague. Of course, the most glaring variation was in the nature of the material. A hardened steel with a high impact value would naturally cause much more distortion of a softer particle than would a softer parent metal with a hard metal sprayed thereon. Other factors included the distance between the spray-gun and workpiece and the angle formed by the line of spray and the surface. Even the degree of roughening had some effect on the particles in the layer immediately next to the parent metal.

Mr. Logan had also raised the question whether vibration or shocks broke down some of the interlocking edges and caused a slackening up process. In general his answer would be that they stood up to vibration. He did not know what particular application Mr. Logan had in mind nor what he meant exactly by his reference to shocks. He thought he had made it clear in the paper that metal spraying was not satisfactory for ball or roller bearings, that is, point or line contacts. But as far as vibration was concerned he did not think any question arose but that the metal spraying stood up under extremely arduous conditions of vibration. The crankshaft was an example. When they considered the success of sprayed crankshafts they could scarcely take Mr. Logan seriously when he said he would feel happier if the coatings were fused. In this country there were something like 50,000 crankshafts metallized today and he was still waiting to hear of failures. During the war he worked on the Crankshaft Reclamation Committee of the Ministry of Supply, where they watched a great deal of crankshaft operation and were naturally associated with a number of operators. One firm in London had done many thousands of crankshafts, and the instances of failure which had come to his notice over a period of twelve years amounted to fewer than a score. As the number of metallized crankshafts in this country was, as he had said, 50,000, this was a very small percentage. He thought he would have heard of it if there were failures, because usually it was the bad things about which one heard afterwards.

As far as bonding was concerned he wanted to draw attention to Table 2 where it would be seen that there was some variation in performance. One had metals like high carbon steel having a very low shrinkage and high carbon high chromium stainless steel almost as good, whereas at the other end of the scale they had brass and iron with very high shrinkages. One tended to select metals with low shrinkage because there was less tendency for them to crack under internal stress during contraction, and less risk of shrinkage damaging the bond.

He wanted also to refer to Table 3 concerning the effects of preparation on mechanical properties. Here it would be seen that when shot blasted with angular steel grit the axial shear and rotary shear values were very low and it was extremely interesting to compare the estimated endurance limit of that type of preparation, 54,000, with that of the plain polished specimen, 41,000. Thus the stress concentration factor had been lowered by shot blasting to 76 per cent of the original for the untreated part. All this was interesting and opened up wide possibilities for the use of shot blasting to pre-stress such things as springs so as to resist fatigue.

The Admiralty had specified shot blasting for crankshaft prepartion. It stretched the surface, and if one started with a stretched surface then the part would not be so likely to fail by reason of fatigue. When the other methods of preparation were compared one could see that each of them had certain advantages, but the point which was outstanding was the shear strength of the bond. It was not when one was putting the bond in either axial or rotary shear but putting the bond in tension, that it was extremely weak, and it would be seen that the applications selected as being suitable for the process made good use of the strength and avoided any use which would subject the bond to severe tension. Since shot-blasting preparation (having a rotary-sheer value of only 3,150lb. per sq. in. in Table 3) had been proved by experience to be satisfactory for crankshafts even under conditions causing seizure, Mr. Logan must surely agree that rotary parts generally would be safely prepared by fusebonding (24,100lb. per sq. in.) or by the "Metco" method of mechanical bonding (25,400lb. per sq. in.). Similarly with reciprocating parts, with the exception of shot-blasting, the figures for axial sheer value provided an altogether adequate margin of safety.

Mr. Freeman had raised a point which had once been considered controversial. He had referred to two schools of thought on the subject of fine atomization. But he could not agree with him that fine atomization in itself could result in stressing the coating; it was rather the reverse. To obtain fine atomization the metal must be heated to a higher temperature at the point where the air impinged on the metal so to produce a very fine spray. Control of atomization with modern metal spraying equipment covered a fairly wide range. It was in fact used for producing gold and silver powders having particular sized particles.

In general, the method of obtaining finer particles was to heat the metal to a greater temperature, but the greater the heating of the metal the greater the oxidization. Not only that, but the finer the size of the particle the greater must be the oxidization in relation to the amount of unoxidized metal in each particle. By means of extremely fine coatings metal spraying could be made to look much prettier and gave it more appeal for decorative work. From that point of view the finer the coating the better. For general coating to prevent corrosion between certain limits, which most classes of equipment could achieve, there was no necessity to go further. When building-up worn parts, he had no doubt on the subject whatever that a fine coating was not desirable, neither for that matter, was an extremely coarse one. Some tried a finer atomization than others, but for built up work a certain medium grain size was best. Below this size whole particles tended to pull away from one another when finishing in a lathe. With a deposit of reasonable particle size one could turn out a good finish. Mr. Freeman had suggested that it was not economical to achieve extreme fineness of spray, and this was quite correct.

Mr. Wilson referred to the patented "Sprabond" process. Sprabond was available in this country now, and he did not think any particular difficulty existed in connexion with it, except the overriding one that it had to be obtained from America. Mr. Wilson had also mentioned shot blasting and had made a rather sweeping statement that most shot blasting in this country was only suitable for working pressures up to 30lb. per sq. in. pressure. He could have agreed with him ten years ago, but if he had in mind the shot blasting equipment installed during and since the war (and shot blasting equipment had a very short life) the statement was not correct. By far the greater number of shot blasting equipments worked at 60 to 80lb. per sq. in. pressure and only a few were working at low pressures, at least in the metal spraying industry. At pressures below 30lb. per sq. in. one could not hope for results good enough for metal spraying.

A job had been attempted recently which he had every reason to think would be successful, and, if so, it would result in a dollar saving which might run into hundreds of thousands of dollars. The company concerned had American tinning machines, which had copper rollers formed by fitting copper sleeves on to duralumin cylinders. Again due to the dollar position the firm had found it difficult to obtain replacements, and they were now attempting to copper spray duralumin forged rollers. Metallizing was saving much dollar currency in many similar cases.

Mr. Wilson's reference to torpedoes was interesting, but he did not know how one judged success or failure of a coating on a war-head on a torpedo. He had asked about the preparation of a flat machined face. He could only refer to the methods he had enumerated in the paper. Flat surfaces were about the most difficult type of work in metal spraying. On a flat surface the spray metal tended to curl up at the edges and corners. But the methods described in the paper avoided this. He must stress that all such work should be carefully supervised. For example, when grooving for the Metco method of shaft preparation they started off with grooves $\frac{1}{64}$-inch wide, and ridges $\frac{3}{64}$-inch wide, and had to stop knurling when these were both equal. If they carried on too far they would defeat their object. If one stopped when grooves and ridges were equal one would have sufficient opening to get the spray metal in. They had yet to find a general purpose machining method of preparing components. Some parts by virtue of their hardness, their shape or their size, could not be so prepared, and must be fusebonded or sprabonded.

The reference to the protection of melting pots was extremely interesting. A great deal of it was being done, not only to protect them from burning, but in some instances metal pots had been sprayed internally in order to give a clean-when-empty effect and also to prevent metals having affinity for steel from sticking to the pot.

Mr. Nicholls had spoken of rotary shafts and the danger of wearing through the coating. Perhaps in the paper he had not stressed that sufficiently, but it was absolutely essential to judge first of all on the part itself how much the permissible wear might be and to obtain any information on the part of the operator as to the maximum possible wear that could at any time be anticipated. Sufficient metal must be removed to make certain that the coating would never wear right through and there should always remain a thickness of not less than $\frac{15}{1000}$-inch. If a metal spray coating should be worn through to a feather edge it would indeed be very bad practice.

Mr. Wilson had mentioned Diesel cylinder liners. Quite a lot had been reclaimed in the manner suggested and all the information he had on the subject indicated that they stood up very well indeed. A number of these had been done just before the war and others quite early in the war, with a view to protecting them against corrosion. The samples which he saw quite recently were in splendid condition.

One speaker had referred to molybdenum spraying under the erroneous impression that this country did not import that valuable metal from America. It could only be imported under licence, and use for the purpose envisaged was the subject of certain patents.

There was no reason why metal spraying should not be employed on land boilers. He knew very little of what had been done on land installations. He did not think contraction would enter into the case. Although corrosion could be arrested by filling in pittings by spraying, but one would have to consider carefully before treating metal spraying as a solution to pitting whether adequate strength remained in the shell. Furthermore, it was necessary to bear in mind that it would be possible for corrosion to be carried on behind the sprayed metal. It would be a risky business because no longer would one be able to see what was happening. It was possible to spray steel on steel, but depending on the potentials of coating and parent metal either could be attacked, and the attack might continue on the shell without being obvious. It was because of that that they had never advocated filling in depressions in boiler plates by spraying.

Regarding Mr. Hunn's queries, the reliability of sand blasting in relation to building-up work was certainly open to question, but the degree of bonding required for general coating work being much less, sand blasting was particularly suitable for that class of work. Reference had been made to American blasting machines in which most of the abrasive was recovered. The same types of machine were indeed made in this country, but in general they were not applicable to work carried out *in situ,* particularly in the case of large structures such as ships hulls. Regarding that class of work, both here and in America it appeared that at the present time some substantial loss of abrasive was inevitable. Mr. Hunn had also questioned the function of coating bronze propellers and shafts with monel metal when zinc spraying a hull, and had apparently assumed that the monel metal was necessary in order to protect the propellers and shafts. However, this was not the case, the reason for the monel being found in its prevention of rapid attack on the zinc which might otherwise be caused by the proximity of the bronze. As far as the application of antifouling compounds was concerned, it was recommended that these be dispensed with altogether when sprayed zinc coatings were employed.

Suitable types of paints had been referred to in the first paragraph on p. 252. Although Mr. Hunn excluded oil fuel as an active corrosion agent, there seemed plenty of evidence that alternating cargoes of any fuel with salt water ballast could give rise to bad corrosive conditions which might be too severe for a metallized coating. As far as electrical conductivity is concerned, there was some loss in the conductivity of the metal when sprayed, but if Mr. Hunn's suggestion was one of insulating value, it would not be correct to assume that sprayed metals acted in any such way. He noted the reference to zinc-rich paints, and while he appreciated that these had considerable value by way of anodic protection, he believed it was true to say that they did not compare at all favourably with metal-sprayed zinc. Mr. Hunn had also enquired the cost of zinc spraying a ship's hull, but of course, cases varied over a wide range because of local circumstances, and particularly the condition of the vessel before preparation. Some recent figures had varied bewteen 4s. and 7s. per sq. ft. of surface treated, including the preliminary blasting and metal spraying with pure zinc to a thickness of 0·010 inch. The availability of an adequate and cheap supply of compressed air influenced costs and another important variant, except when the work was carried out under cover, was, of course, the weather.

Col. McCullum had given support to the author's conclusions. He was sorry that to date the ratios of welding electro-deposition and metal spraying in his works was still 5 : 3 : 1 but was glad that Col. McCullum had accepted the process both for suitability and cost for certain classes of his work. The remainder of Col. McCullum's contribution indicated how he had investigated the metallizing process. He agreed with all he had said and he thought that his explanation of the efficiency of sprabonding compared with grit blasting, was largely correct, while his final conclusions were very good, and if followed closely would yield first class results.

Mr. Robinson drew attention to what he called a serious weakness in the reliance on mechanical interlocking of the torn edges of the particles, and suggested that the reliability of the process depended on it being carried out by experts. Again, he could only say he had endeavoured to point out this weakness of sprayed metal and to explain that it was inapplicable to the classes of work recommended in the paper. He would say, therefore, that Mr. Robinson would be well advised not to use the process for the purposes for which it was not recommended, otherwise the suggested weakness might apply to the process. Mr. Robinson's suggestions seemed rather like someone making the bold statement that welding should not be used because it could damage articles by heat distortion. Such an argument was disproved by the fact that welding was employed on many classes of work in which distortion could be avoided, or in which distortion would not occur or would not matter. The same was true of metal spraying. Again, one might be tempted to say that welding should be carried out by experts, whereas it was equally true of both welding and metal spraying that some classes of work required specialized experience, whereas others could be carried out equally by a man who had been taught only the rudiments of the process. Prohibitions relating to metal spraying and indeed to welding could still be found in certain quarters, but experience spread and even the most conservative works did in time make use of processes that they had previously regarded as hazardous.

Com'r Stewart had raised a very important point regarding cleanliness of prepared surfaces. A microscopically thin film of oil such as was left after attempting to remove oil by washing with solvent, could detract very considerably from the bond-strength achieved. A film of grease had some cushion effect on the particle when impact occurred. It also increased the possibility of slip and even ricochetting rather than instantaneous anchorage upon impact. When grease was interposed between the coating and base material, the shrinkage of the former could result in relative movement between coating and base over the greasy area, which would not occur if the two metals were in intimate contact. Of course, in the case of protective coatings, the importance of metal to metal contact was not only a matter of bond srength, but generally primarily one of making certain that no interposed layer of foreign matter could interrupt the free flow of electrical energy associated with galvanic action.

Com'r Stewart had referred to work carried out on one of H.M. ships during the war, and had had limited success with the reclamation of brass or bronze spindles from centrifugal water pumps. He had used shot blast sometimes and rough turning at others, whereas neither of these preparations were satisfactory with brass or bronze, since the strength of any barbs or projections formed on the parent metal was extremely low. Under such circumstances cleanliness became a vital factor. However, the same work could have been carried out with complete success, if the "Metco" technique of shaft preparation as described in the paper and shown in Fig. 8 had been employed. Com'r Stewart's question concerning the reclamation of parts running in soft-packing glands was an excellent one, because conditions could be very severe. The answer was that metallizing was suitable—the appropriate preparation being grooving followed by knurling with the special shaft preparation tool. The insert of sprayed metal should extend beyond the working surface, and the finish was preferably carried out by grinding. Assuming reasonable operating conditions with lubricant available it was found that the sprayed metal stood up well, but under dry-rubbing conditions, after the exhaustion of any lubricant held in the pores of the sprayed metal, the sprayed metal would break-down quicker than solid metal. However, even with infrequent greasing, a sprayed shaft held the lubricant for long periods, whereas a solid shaft was rapidly wiped dry. Failure of a properly prepared coating would not mean that the coating would break away from the shaft, but that under the severest conditions of dry-rubbing wear might be much quicker than with solid metal. Thousands of such glands had given long service after metallizing. An interesting problem in which both solid and sprayed metal had previously failed, was solved by spraying the asbestos-packing with a light coating of babbit-metal—and thereafter a reasonable life was secured. Com'r Stewart was correct in assuming that the incidence of failure increased with temperature above minima varying with different metals, but any lowered coefficient of heat transfer did not result in any obvious disadvantage within the classes of work discussed. One could, however, envisage circumstances under which it might assume some importance, but abnormal work of that kind was not, he hoped, usually carried out until it had been established that the process was suitable for the particular conditions. Sprayed copper had been used inside Diesel-engine pistons to conduct heat from undesirable areas with some success, and there were other applications where it was used to advantage as a heat-conductor so that it should be borne in mind that reference to lowering the coefficient of heat-transfer was made relative to the same metal in the solid state. Indeed, where desirable, glands subject to considerable heat could have part of the rod metallized with a better conductor than the base material with beneficial results.

Mr. Zubiaga had supplemented the replies given to Mr. Gibson and Mr. Clark. He had also shown that the test figures quoted in the paper, were, like all laboratory results, open to the objection that they did not duplicate service conditions. In this case, however, the tables erred on the safe side by reason of the small diameters employed against which all methods of preparation were rather drastic. However the figures given were intended to convey only the relative merits of various preparation processes, and they would be misleading if interpreted as applying equally severely to large shafts. Mr. Zubiaga had certainly made it abundantly clear that in Spain marine engineers not only had confidence in the metallizing process but that they used it to advantage. The example of the reclaimed tail-shaft which combined salvage with protection against corrosion certainly seemed worthy of note.

MEMBERSHIP ELECTIONS

Elected 10th January 1949

Members

Karl Gunnar Anander
Sven Berntsson
Frank Broughton
Neil MacNaughton Brown
Raymond William Brown, Lt.-Com'r(E), R.N.
Alexander Clark
Wilfred Alfred Cook
Arthur Herbert Victor Chiverton, Lt.(E), M.B.E., R.N.
William Robert Corner, Lt.(E), M.B.E., R.N.
Clement Arnold Fernandez
John Edward Pakenham Grant
George Harrold
Walter James Isaac
Frank Edwin Charles Jarrett
Sten Johnsson
Peter MacFarlane McWilliams
William Arthur Skinner Pearson
Rudolf Redner
William Reginald Sabine
Anders Sjögren
George Withell Strong
George Howard Turner
Winston Allan Sullen
Philip George Whittle, A/Lt.-Com'r(E), R.N.
John Wormald
John William Ward
Peter John White
Donald Edward Wilson
John Wood
Shalaby Zakaria El. Sayed

Associates

Edulji Rustomji Dastoor
George Jack Fairley
Henry Frank Jarrett Higgs
Allan Kitchen
Alan John Nathan

Students

Richard Rayner Pilcher
Ronald Webster

Transfer from Associate Member to Member

Bal Krishna Gupta, Lt.-Com'r(E), R.I.N.R.

Transfer from Associate to Member

George Thomas Richardson Campbell
Robert Angus Rollo Carstairs
Alexander Hanna
Denis Lawrence Munro
Harold Parker
Alfred James Pover
William Hendry Semple
Carlo Ignazio Smoquina
Rodger Walker, D.S.M.
Harold Whincup
Kenneth William Williams
Dady Jehangir Writer

Transfer from Associate to Associate Member

Geoffrey Eyre
William George Smith

Transfer from Student to Graduate

Laurence Reginald Holloway

Steam Gunboat Machinery—A Light-weight Steam Plant

Com'r(E) H. A. K. LAY, R.N. and Com'r(E) L. BAKER, D.S.C., R.N. (Member)

Discussion

Mr. W. Sampson (Member) said that he understood he had been given the opportunity to open the discussion because of his connexion with the Institute of Marine Engineers, and on behalf of the Institute he would like to say that they appreciated the compliment.

Perhaps the most significant item in the paper was the authors' statement under the heading "General", that after five years of war service an investigation showed that every important item was still in good condition; the light scantlings had nowhere set a visible limit to future life.

Even though this was qualified by their statement that the actual steaming hours of the vessels were only a fraction of those of major warships, they brought out the point that not all the wastage troubles of the latter were related to the total steaming time.

With the record of these successful installations before them, designers should thoroughly examine conventional mercantile standards and practice, for the paper showed clearly what great gains in weight and, of course, cost could be made without involving any risk.

The long-accepted factors of safety could be a real penalty if they were not judiciously applied, and with a view to adding further detailed information to that given in the paper he might perhaps be permitted to give the following facts regarding the boiler design.

In the Foster Wheeler boiler the tube thicknesses were as follows: fire tubes in front of the superheater and water-wall tubes, 1½-inch outside diameter, thickness 0·104 inch; the remainder of the boiler generating tubes 1-inch outside diameter, thickness 0·081 inch.

Classification Societies' rules included a corrosion allowance; but surely a corrosion allowance on the whole surface of the boiler tubes was a penalty that did not in fact give much longer life, for corrosion in most of its forms was local in character and of a speedy penetrating nature, and the longer life due to additional thickness was almost negligible. It seemed, therefore, that to thicken up the whole of the boiler generating surface was not a true requirement, but that purity of feed, de-aeration and chemical treatment was.

The water drum in Fig. 6 was only 18-inch diameter, the steam drum 33 inch in diameter, and the wrapper plate of the steam drum was made $\frac{9}{16}$-inch thick, working to a stress of 14,000lb. per sq. in. The plain end was ⅝ inch and the manhole end ¾-inch thick, being dished to a radius of 23⅞ inch with a knuckle radius of 2¾ inch. The drum was built throughout of 28/32 tons per sq. in. steel to Admiralty specification.

These figures have been given because, looking at the illustrations in the paper, one might wonder how these very light weights were achieved. The actual scantlings were very interesting.

It would be enlightening to speculate how improvements made since 1940 would make possible still lighter machinery, and he thought that boiler designs could be made lighter today because of the possibilities in sight in respect of improved combustion methods, etc.

There was every prospect that the furnace heat release rates given by the authors could be raised to at least 500,000 B.Th.U., or even higher, which meant, of course, a reduction in furnace volume and consequently in the weight of boiler.

Secondly, with boilers in an open stokehold of cased design, and the acceptance of much higher gas velocities through the boilers, higher transmission rates would be possible, effecting a reduction in total heating surface.

Thirdly, the substitution of a certain proportion of the boiler heating surfaces by light-weight aluminium economizer surface, as now used in other naval vessels, would effect a substantial reduction in total weight.

Fourthly, it would be noted that the brickwork and insulation accounted for no less than 25 per cent of the dry weight of the Foster Wheeler boiler, and reduction in this weight would be made in a new design by more water cooling of furnace and the use of lighter weight refractories.

Although an actual example had not been worked out the boiler weights might be reduced by the foregoing means quite substantially.

In conclusion, the very many novel features of design, leading to the attainment of the lightweight machinery which had been described, ought to have a very marked effect in naval design generally, and certainly to a lesser degree in vessels designed for the merchant service.

Rear-Admiral (E) G. H. H. Brown, C.B.E. (Vice-President) said that in making comparisons between the steam gunboats and other light warships it was necessary to bear in mind that these ships were built for a particular service, with a limited scope, and no attempt was made to provide the same degree of reliability and availability that was expected of a destroyer or a frigate; the auxiliaries were not duplicated, and the usual safeguards to provide for continued operation after sustaining action damage were omitted. In fact, the ships were intended to be serviced at a shore base. At the same time, the utmost was done to make them as reliable as possible, without recourse to the usual duplications and shut-offs which were fitted in normal warships.

Perhaps the most interesting features of the design were the numerous devices adopted to reduce weight, which gave scope for the exercise of very much ingenuity. In particular he would like to mention the combined forced-draught fan and oil-fuel pump, which was, he thought, an outstanding example, and also the method adopted for supporting the circulation pump of the La Mont boiler. The extent to which interchangeability was achieved between two boilers of such dissimilar type was a very noteworthy feature. Notwithstanding their high rating and reduced scantlings of both pressure parts and casings, the boilers gave very excellent service. He had particularly in mind the natural circulation boilers which, after about two years of service, revealed remarkably little wastage.

He would like to endorse Mr. Sampson's remarks about the corrosion allowance for tubes. He thought there was much to be said for reducing the thickness of tubes in order to reduce the heat stresses. There was very little to be gained by increasing the thicknesses of tubes purely to combat corrosive attack which in general was very local.

The saving in weight achieved by the use of light pipe flanges, coupled with their reliability and freedom from leakage, was most gratifying.

Of course, if the job had to be done all over again there were undoubtedly many features susceptible to improvement, but he thought that, having regard to the short time available in which to design and produce this machinery, the results achieved were really remarkable and reflected great credit on all concerned.

Mr. H. N. G. Allen, M.A., A.M.I.N.A. (Member) said that he regarded as the most significant statement in the paper the fact that, in spite of the special circumstances and conditions for which the ships and the machinery were designed, after quite a considerable life everything was found in reasonably good condition and the light scantlings had not set a limit to the life of the machinery; this was in spite of the fact that the power-weight ratio had been reduced from 31lb. per s.h.p. to 14lb. per s.h.p.

The question therefore asked immediately was whether the results from the machinery in this special application justified a substantial move towards higher power-weight ratios in less specialized craft, bearing in mind the fact that in the more conventional type of craft one had to lay different stress on reliability, durability, simplicity, ease of maintenance and efficiency. He felt that there was considerable scope for moving along those lines, but he would like to know the authors' views on the matter.

The second point was that tremendous progress was made on this job in a very short space of time, which was possible because certain existing standards were relaxed, in view of the special circumstances. Whilst realizing that, especially in a time of emergency, one must freeze a design and secure standardization and complete interchangeability, it did seem that in normal times, if rapid progress was to be made, the specifications for machinery should be as flexible as possible to allow scope to designers, whilst maintaining, of course, certain essential basic standards.

Thirdly, in the aeronautical engineering industry vast sums of money had been spent on research and development during the past twenty years, which must be the envy of most marine engineers. It did seem that, in spite of the very different outlook between aeronautical and marine engineers and the very different requirements for which they were designing, there was nevertheless a great deal of scope for them to get together to see whether the marine engineer could not veer even by a small amount towards the outlook of the aeronautical engineer. He felt that, if power-weight ratio was to be an important factor in the design of machinery, the immediate need was for the marine engineering industry to apply existing knowledge to their own art and science in a very determined fashion, rather than to be questing mainly after new knowledge. A tremendous amount of the knowledge which had been gained, especially during the last war period, had yet to be applied.

In the case of prime movers, apart from the gain that could be made in power-weight ratio by higher steam pressure and temperature conditions and high rotational speeds, he would like to know whether the authors agreed that one of the most important factors was to aim at the greatest degree of symmetry in the design of prime movers so that thermal stress could be reduced to the absolute minimum. He felt that if they could be reduced the minimum weight could be cut without affecting either strength or rigidity.

Turning from rather general questions, there were three small practical questions he would like to ask. First of all, among the auxiliaries fitted in these ships the steam turbine ones were divided into two classes, those which were direct-driven and those which were gear-driven. The boiler circulating pump, the feed pump and the generating set all had direct-drive turbines. But they were machines which were running continuously when the vessel was at sea. He would like to know the factors which determined the decision to have these sets direct-driven rather than gear-driven, for it would appear at first sight that the gain in fuel consumption as the result of gearing them might have saved bunker space and, therefore, weight.

The second practical point was whether in view of the fact that normally trained Service personnel were manning these ships, any difficulty was experienced with the handling of the very small parts. He was thinking of very small nuts and bolts with B.S.F. threads, etc.; was any difficulty experienced in the handling of these by people who were accustomed to maintaining very much heavier machinery? Was there any experience of bolts being broken off, or of valve spindles having their necks screwed off?

Finally, in comparison with machinery of corresponding output and of more conventional design, was the maintenance time required on the individual machines greater, and was the frequency of overhaul greater than was expected with conventional machinery?

Capt. (E) W. K. Weston, R.N. (Visitor) said that as the authors had said, the design was skimmed to a limit in order to meet certain weight requirements, and, as he thought was inevitable in the circumstances, the process of skimming undoubtedly went too far in some directions.

He had three points in mind.

Firstly, the ships fitted with La Mont boilers never attained their full designed shaft horse-power. The first such ship, when on trials, did not reach 7,000 s.h.p. (the designed power was 8,000 s.h.p.), and even when the fuel-burning equipment was altered and the furnace volume increased the next La Mont boiler ship only achieved something like 7,200 s.h.p. On the other hand, the ships fitted with the Foster Wheeler boilers achieved the full designed power without much difficulty, and all marine engineers would understand his meaning when he said that these ships felt altogether sweeter to drive at full power than did the La Mont boiler ships. The Foster Wheeler boilers were, however, 2 tons heavier; that made all the difference.

The lesson to be learnt from this was that even when weight must be cut down as much as possible, it did not pay to attempt to design a boiler without allowing a margin on the output.

The second point was that there was no auxiliary feed pump. The main feed pump was fitted in the engine-room, and all that the stoker petty officer in charge of the boiler-room could do if there was a feed failure was to bring the boat to a standstill. As the boats were intended to operate just off the enemy coast, this was bad for morale. In a future design of this sort an auxiliary feed pump was essential. The question was investigated of fitting one later on, but for various reasons no action was taken. Incidentally, the cruising radius at low power could have been increased enormously by the use of a small auxiliary feed pump instead of the turbo-driven main feed pump.

Thirdly, the authors referred to the trouble experienced with corrosion in superheater tubes, and they seemed to suggest that one had just to put a little United States Navy boiler compound into the feed water, and all was well. This was a cause of contention at the time, and his personal opinion was that the trouble was eventually cured by the improvements which were made in the design of the evaporators. The original evaporators were very small units, and even on shore trials they only produced feed water just below the maximum specified salinity. At sea, with an unsteady platform and perhaps rather rough operation, they proved to be too small for the job.

Mr. G. A. Plummer (Member) said that as one of those associated with the design and construction of the forced circulation boilers referred to in the paper, and having some little experience of the early history and subsequent performances of those units, he would like to refer to one or two points.

A large number had been installed by the German Navy; a few were used in land installations in this country, and there was a very early one in the destroyer H.M.S. *Ilex*; so that there was some background. But nothing approaching the small weight and size of the units discussed in the paper had ever been attempted before; therefore, much new ground had to be broken.

The boiler itself was designed around the combustion apparatus, and the ability of that apparatus to deal with the fuel within the confines of the combustion chamber limited entirely the size to which the unit could be reduced. The effects of low viscosity oil were not fully appreciated; premises were based on Admiralty burners or sprayers which had been tested with normal fuel oils. The authors inferred that the combustion chambers, particularly of the forced circulation boilers, were over-cooled; and they were not alone in that opinion at the time. As a result, during the early tests on the prototype unit, about 20 per cent of the furnace cooling tubes were covered with refractory tiles. If the authors would refer to the test results obtained at that time they would see that the reduction of the cooling surfaces in the combustion chamber had no beneficial results whatever on combustion. The only results, he would say, were higher uptake temperature and reduced flexibility of the units. He expressed the opinion then, and further experience confirmed it, that, given sufficient heat to promote ignition, and further effects were the result of, and not the cause of, combustion, and he was convinced that advanced designs must employ the maximum amount of combustion chamber cooling surface.

This matter was dealt with more fully in a paper entitled "The Development of the La Mont Boiler in Great Britain"*. He suggested that the difficulties in 1941 were largely overcome by improvements in atomization and attention to air distribution and direction. Given forced circulation, the main criterion for small size boilers was the ability to burn the fuel in the minimum combustion space.

Considerable improvements in technique had been effected since 1941; the rates of combustion which were then considered high were mediocre in these days. Forced circulation boilers had since been built with much greater combustion rates; and the limit was not yet reached. They had only to consider the combustion rates achieved in jet aircraft engines to appreciate what were the possibilities in this connexion.

Although the authors had ably demonstrated that they were well-skilled in the art of getting much into little space, this had perhaps precluded reference to many interesting features. He had in mind, for instance, the use of stub tubes in this work, probably the earliest example in this country; the large use of welded construction; the use made of heat-resisting steels to reduce weights; the very large use made of up-to-date knowledge in respect of insulation and refractories; and the outstanding dryness of the steam from the La Mont boiler. The last point, however, had been referred to in a previous paper by Com'r Baker†. He was gratified to see the reference to the satisfactory behaviour with sea-water feed; and he would like to amplify the authors' remarks by reference to a further case, where three small high-explosive shells penetrated a boiler. The boiler was staming at a pressure of about 400lb. per sq. in. Several tubes were flattened or distorted, but not a single failure occurred. The ship steamed home, but no tube became over-heated, despite the reduced area due to the flattening of the tubes.. It had to be borne in mind that sufficient water was kept passing through that tube afterwards to prevent it burning out.

Many improvements had been made as the result of steam gunboat experience, and they were now being incorporated in merchant ships.

Mr. H. J. Grout, B.Sc. (Visitor) said that for three years he was engaged as an engineer officer in operating these ships in the Channel, so that perhaps he might give a brief account of difficulties experienced in those days.

First of all, he thought a major mistake was made during the early trials carried out from the Clyde, in that the first two or three steam gunboats were not taken out in heavy weather and steamed continuously for 50 or 60 hours. They normally went out to do speed trials, but as soon as it blew up a bit, everyone said it was not possible to do 30 knots in such weather and they would have to return. They soon found out, that although the machinery operated extremely well in smooth water, on the first trip through the Irish Sea, during a gale, all sorts of unforeseen snags arose.

He had in mind particularly the operation of the distilling plant; this piece of machinery just refused to operate in rough weather, particularly when the ship was rolling and steaming at low speeds. The suction to the evaporator pump was taken in through the hull only about 2 feet below the water-line, thus while rolling heavily this intake came out of the water causing an intermittent and variable flow of make-up sea water to the evaporator; in consequence there was very heavy carry-over into the boiler. He thought that the corrosion troubles in the boiler plant were largely due to the bad performance of the evaporators in the early days, before they were modified.

The second point was that these vessels had no spare auxiliaries of any sort; this meant that if a ship were, say, half a mile off the French coast at night and the feed-pump went out of action, as it did on more than one occasion, the vessel had either to be towed back or signal for help. They were very much afraid of feed-pumps after one or two such incidents. These defects were mentioned to the Engineer-in-Chief's Department on two or three occasions, but apparently there was no easy way to get around the problem; eventually, however, by fitting a new type of centre bearing it was possible to increase the number of running hours without breakdown from about 300 to 1,000 or so.

He thought the oil-fuel burning equipment and the combustion chamber ratings of these boilers was definitely too high, with the result that at full power on a dark night one could see what was apparently a sheet of flame coming out of the funnel; this tended to reduce morale. Flaming from the funnel was very definitely bound up with the fuel oil mixture, if Pool gas Diesel mixed with the right amount of a heavier grade was used it was possible to get away without too much difficulty; but if they had to move at short notice to a new operating base, as did happen from time to time, and they had not the proper fuel but only ordinary Pool gas Diesel oil, the combustion problem became a little difficult.

Altogether, however, he felt that the experience gained in constructing and running these ships had meant that if they had to build similar vessels in the near future, he was sure that both D.N.C.'s and E.-in-C.'s Department could produce a vessel which in every way would compete with the motor torpedo boats which held the field for work in coastal waters during the last war.

Mr. W. J. Ferguson, M.Eng., M.I.N.A. (Member) said that since the very great reduction in weight was in some small measure the result of the acceptance of higher stresses, it was inevitable that some one would ask what the classification societies were going to do. He suggested that if the Admiralty would let them have particulars, they would see what could be done.

One should not anticipate great changes in the rules of the classification societies because conditions were so very different. There was not much incentive to save machinery weight in the average merchant ship; there was not very much incentive to save space, limited as one was by certain tonnage regulations regarding the size of an engine-room. But there was always an incentive to save something on the initial cost of the machinery installation, provided one would not thereby add to the repair bill during the life of the vessel.

Examining the fact he felt certain the authors would agree that the percentage of the saving of weight which was directly attributable to higher stresses was very small. Much more important was the sacrifice of certain auxiliaries, in view of the very special conditions applying to these ships. Further, these vessels had had five years of service at the most, and he imagined that during those five years the total steaming hours would be very much less than in the case of a merchant ship over a similar period. In the merchant service one designed for a longer life.

Under the heading "Boilers" and the sub-heading "Design Limitations", the authors stated that the only relaxations from standard stress allowances, etc., were that the Admiralty standard drum and pipe stresses could be increased 10 per cent and that flange thicknesses could be reduced 10 per cent. Everyone had seen designs in which, at points of maximum stress, more careful design could have reduced the stress by at least 10 per cent; and the explanation might be that by careful design, the avoidance of stress concentrations, etc., the designers had increased the basic stress without in fact increasing the maximum stress at all. One could not say, without a knowledge of the complete design. In other words, the saving might well have been due to skilled design rather than simply to the reduction of thicknesses throughout. He felt quite certain that that would be the aim of the designers, and he thought it was only fair to say that classification societies in general would not abide rigidly by the letter of the law, but were always leaning further towards intelligent design.

Many items came to mind. For instance, there was the design of end plates, which were among the highest stressed parts of the boiler drum. In pipe work the basic stress was extremely low; nevertheless, in actual service the pipes could be stressed very highly.

Regarding the thickness of tubes, he agreed that there must be room for a very considerable reduction below what was

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* Plummer, G. A. 1946 Proc. I. Mech. E., vol. 155, p. 346 "The Development of the La Mont Boiler in Great Britain".

† Baker, L. 1947 Trans. I. Mar. E., vol. 59, p. 57 "The Dryness of Steam and Priming in Marine Boilers".

stipulated in the printed rules, for example. But in fairness he would point out that in practice there had been in fact a very considerable reduction during the last six or eight years, and that with the advent of higher pressures one was just forced to accept tubes having a wall thickness less than that given by the old formula. The successful experience with thinner flanges was of great importance, although one could have wished the experience had related to a steam temperature in excess of 700 deg. F.

He was not quite sure that one was right in referring to the corrosion "allowance" in tubes; the fact that there was a constant in the formula did not necessarily mean that it was a corrosion allowance. One needed a formula which would cover a wide range of diameters, and the thickness of the smallest tubes must be such that they could be handled, and expanded, and therefore, the thickness was not in direct proportion to the diameters. There must be a constant, but it was not of necessity a corrosion allowance.

In the case of drums, headers, etc., in the merchant service, he thought there was a lot to be said for a corrosion allowance. He agreed that it was important to take care of water treatment, but during a life of 25-30 years it was probable that at some time conditions would be favourable to corrosion. Most of them had seen boilers in which bad pitting had occurred at some time, had been arrested, and the boilers had continued in service due to the provision of a corrosion allowance.

He was glad to note that the stress in the screw shafting of these ships was not increased above the normal. That was in line with their own experience; they felt that there were sufficient failures of screw shafts to justify their belief that their basic stress was about right.

Mr. M. C. Dunstan, R.C.N.C., A.M.I.N.A. (Visitor) wrote that the steam gunboats described by the authors were designed in the department of the Director of Naval Construction under the direction of Sir Stanley Goodall who was the D.N.C. at that time. The naval constructors were presented with the problem of designing a craft to defeat the German "E" boats; a high top speed was essential, but an important factor determining the choice of steam was that it enabled maximum speed to be maintained continuously, whereas the internal combustion engines in the "E" boats would allow maximum speed to be maintained for short bursts only. It was thus hoped to be able to overtake the "E" boats and bring them to action.

The steam gunboats were designed with good sea-keeping qualities to enable them to operate at high speed in the Channel in a seaway.

As the design progressed it was found that a weight of 50 tons only could be allowed for the machinery; the Engineer-in-Chief was asked to investigate the possibility of designing a complete machinery installation within this weight to develop 8,000 s.h.p. The paper described how well the work was carried out.

There was no doubt that this new machinery problem threw a spotlight on many items of machinery equipment which had previously been accepted as standard items, but which now had to be redesigned to obtain a reduction in weight. The manner in which the lighter redesigned equipment, and also the standard equipment to lighter scantlings, stood up to service was most encouraging. The research work devoted to these craft, and the experience gained on service, would be well repaid if it had made possible the reduction in weight, without loss of efficiency or reliability, of machinery installations in future designs.

It could be added that the hull designs of the steam gunboats proved to be entirely satisfactory. It would be of interest if a few of the officers who served in these craft would give their opinions on the efficiency of the vessels as fighting units.

Mr. H. Hillier, O.B.E., M.I.N.A. (Member), wrote that the particulars of pipe flanges given in Fig. 10 were for the high pressure piping. The saving in weight obtained with the low-pressure piping was equally significant.

The use of high tensile steel bolts with fine threads permitted the bolt size to be reduced considerably without risk of the bolts being broken by maltreatment. The practice followed in this respect could, he suggested, be adopted in much bigger ships without any operational difficulties and with a very appreciable saving in weight throughout the ship.

The development work which was carried out in connexion with the evaporating plant was found to be particularly valuable later in the war because for operations in the Pacific it was found desirable to provide much larger quantities of fresh water than could be provided by the distilling plants which were fitted in many of the ships when built. The King George V battleships, some of the aircraft carriers, and some of the larger destroyers, were therefore fitted with several emergency evaporating plants having outputs of 10 to 15 tons a day, the designs being based on the proportions which were developed for the steam gunboats. The comparatively small space occupied by these plants permitted them to be fitted in machinery rooms which were already very congested and in which it would have been quite impracticable to fit distilling plants of normal design for the same capacities. The experience gained, therefore, in connexion with the steam gunboat machinery, enabled the distilled water output in the larger ships to be augmented very considerably, very quickly, and with a small increase in weight, the small physical size of the plants being the vital factor which enabled them to be fitted in the small corners which were available.

Com'r (E) F. J. King, M.B.E., D.S.C., R.N. (Member) wrote that the following referred to the unsatisfactory results of one of the devices used to secure reduction in weight and space of the steam gunboat boilers. This was the rating up of the furnace of the John Thompson-La Mont boiler to $0{\cdot}343\times10^6$ B.Th.U. per cu. ft. per hour, which, though excusable in the light of existing knowledge at the time, was a mistake as it was specified on the false assumption that the combustion equipment could produce this heat release rate. Later experience indicated that the poor combustion experienced in this boiler was basically the result of this error and only indirectly due to the fact that its furnace was fully water-cooled.

It was certain that the combustion equipment used in the steam gunboat boiler could not give a heat release rate greater than $0{\cdot}25\times10^6$ B.Th.U. per cu. ft. per hour, and if combustion was to be complete within the furnace it was essential that the furnace volume should be decided on this basis. In the case of the shore trials of the highly rated three-drum boiler, when oil was burnt through similar combustion equipment at a rate of 17·6 or more lb. oil per cu. ft. per hour of combustion chamber volume, combustion within the tube bank undoubtedly occurred. A furnace rating of 17·6lb. oil per cu. ft. per hour of combustion chamber volume did not correspond to a heat release rate of $0{\cdot}343\times10^6$ B.Th.U. per cu. ft. per hour if a considerable proportion of the flame was in the tube bank. On the other hand, if a combustion chamber was over-rated from the aspect of heat release rate per unit volume, impingement of partly burnt oil droplets on the tubes and brickwork would occur in proportion to the over-rating, and the effect of this on heat release rate must be worse if the impingement was on relatively cold tubes than if it was on brickwork at a temperature approaching the flame temperature. To this extent the fully water-cooled furnace would be at a disadvantage since, for example, an excessively long flame would impinge upon a back wall of tubes instead of brick. Experience showed that even in furnaces with a back and floor of brickwork, similar impingement troubles could occur with over-rating if the side clearance between wing registers and adjacent tube walls was not ample. If freedom from combustion trouble was to be ensured, and if the design conditions for gas temperature within the boiler heating surfaces were to be achieved, the specified combustion chamber rating should never exceed the heat release rate per unit volume of which the combustion equipment was capable; moreover, it was necessary to specify a minimum clearance between wing registers and adjacent tubes dependent upon the diameter of the flame from a single sprayer. Comparative trials with sprayers and registers of naval type burning into the open and into a boiler furnace showed that there was no marked difference in heat release rate under the two conditions of temperature of the flame surroundings. If therefore the design conditions were suitably specified, there was no reason why the performance of the fully water-cooled combustion chamber should not be quite as satisfactory as regards combustion as the partially cooled variety. A pre-requisite, if weight and space were to be saved by rating up the combustion chamber, was to develop the combustion equipment to give the necessary increased heat release rate.

Mr. E. L. Denny, B.Sc., A.M.I.N.A. (Visitor), wrote that from the beginning it was realized that, if weight was to be saved, very much higher stresses would have to be accepted.

The makers of auxiliaries were given a very free hand and achieved very fine results, both on the score of weight saving and reliability.

In regard to the main machinery and connexions, he was of the opinion that even higher stresses could have been accepted with a view to further saving in weight, and even the provision of numerous emergency and standby connexions could be dispensed with in a vessel of this nature.

Unfortunately, as the war was still at its height, it was deemed undesirable for various reasons, to take undue risks; nevertheless, the final results could be considered as a very great advance on any existing vessels of similar type. Indeed the reduction of the propulsive weight of the machinery for an 8,000 s.h.p. installation of 50 tons was, indeed, no small achievement.

It was unfortunate that the speed of the vessels, due largely to increase in armaments carried and to service equipment, was not as high as was originally anticipated, but as the sea-keeping qualities of the vessels proved to be better than anything of a similar type afloat, he thought they instilled a very wholesome fear into the minds of the "E" boat commanders.

If the authors could have given some particulars of the full power trials he thought the value of the paper would be greatly enhanced.

The comparison of the weights and outputs of the natural and forced circulating boilers fitted in these vessels was very interesting indeed, but the length of service of the various units was not long enough to enable a very definite decision to be arrived at by considering their relative merits and demerits.

The Authors' Reply to the Discussion

Com'r(E) H. A. K. Lay and **Com'r(E) L. Baker** in reply wrote that it had not been their intention to invite criticism of the the classification rules, but the point had been raised in the discussion. Mr. Ferguson had dealt with the comments to some extent but the justification of a constant in the formulæ did not seem to bear investigation. It was of course agreed that a minimum thickness appropriate to a given tube size and method of attachment was necessary, but surely this was better provided by omitting the constant from a formula and laying down the minimum wall thickness?

In general, to designers of plant in which extreme lightness and compactness were of less import than very long life and low initial cost the main interest of the present subject would probably be in the possibility, mentioned by Admiral Brown, of reducing thermal stresses where other considerations permitted reduced scantlings. No doubt the Admiralty would be very pleased to give Mr. Ferguson all the information regarding the designs and the subsequent experience with the boiler of each type now installed at the Admiralty Fuel Experimental Station, Haslar.

Mr. Allen's questions were most appropriate to a combined meeting of naval architects and marine engineers, particularly his first one, as to whether the results in this rather special application justified a move towards higher power/weight ratios in larger craft.

The authors agreed that there was much scope for improved power weight ratios in conventional craft without sacrifice of reliability; the matter of weight saving should always be in the forefront of designers' minds, and principles, as well as details, should constantly be examined with weight reduction in view. For large scale production it might be necessary to effect considerable changes in present manufacturing techniques.

If the continued reduction in machinery weight were pursued with determination there would ultimately come a time when in each type of vessel careful consideration would be required as to whether the policy throughout the vessel was consistent. It would be necessary to assess whether the cost in money and technical effort of obtaining further reductions in weight would be best expended in this or some other direction, having in view the qualities of the ship as a whole.

The lighter and faster the craft, the more important machinery weight savings became; and when an endurance at given speeds was specified, the weight of fuel required must be considered together with the actual machinery weight.

It was unfortunate that in marine engineering the size and cost of machinery units and the limited production numbers, together with tradition, had in the past resulted in a minimum of full scale development and testing. Progress had accordingly been in small steps. Under these conditions, too rigid a specification retarded progress. The steady research and development which it was hoped would take place in the future would enable progress of the product to proceed in jumps, with standardization between each jump. This standardization, to a rigid specification, was essential to ensure satisfactory operation of a fleet, interchangeabiity of parts, and to allow of rapid expansion in emergency.

The problem of utilizing in naval machinery practice the outcome of some of the vast amount of research which had been undertaken in the field of aeronautical engineering was too wide to deal with adequately at this point; although the connexion of the matter with lightweight steam plant was very real. Much of the knowledge which had been gained by such research and development, must have application specifically to items which had, by marine standards, short life and small size, and which were suitable for quantity production and special tooling; and which required specialized operatives both in production and more particularly in maintenance. The desirability of sifting existing knowledge and applying it to marine engineering, and in particular naval engineering, was very fully agreed, but they considered that for such a process to be fully beneficial it was necessary first to have clearly in mind the qualities of a plant to which most importance was to be attached; and to decide this, a broad overall survey was necessary. The determined application of existing knowledge was certainly fully as important as the quest for new; it was believed the two should proceed side by side.

Mr. Allen pointed out that some of the turbine auxiliaries were direct driven. A considerable weight saving would have been effected if the circulating pump of the forced circulation boiler had been geared; but the design of this pump had to be finalized at a very early stage, as it was built into the boiler, and the time for development was therefore less even than for the other auxiliaries.

The gearing of the turbo-generator unit was considered and a tentative design with gearing produced. The output of the machine was very small—only a few kilowatts, and after the designed speed of the dynamo had been raised to 3,500 r.p.m. it was found that the complication of adding gearing would not in this case bring an overall advantage.

The direct drive feed pump ran at 7,500 r.p.m. and it was doubtful whether much would have been gained by gearing that particular unit, although the matter would have to be carefully re-considered if a pump with similar duties were to be designed again.

The naval ratings in these vessels quickly learnt to handle machinery which was of lighter scantlings than in conventional naval plants. In such small vessels the proportion of skilled to unskilled ratings was higher than in larger ships, and this undoubtedly was an advantage in this connexion. It was impressed on those concerned that care was necessary; for instance the very thin pipes could be damaged seriously if stood upon. One firm building auxiliary plant selected for certain work men who owned motor-cycles; these had already acquired the "feel" for avoiding the over-tightening of small bolts.

It was thought that in general the frequency of overhauls required was not significantly greater than in more conventional machinery; but the experience with the vessels was rather too short to be sure of this.

Referring to Captain Weston's remarks, the machinery was designed to be as light as possible without passing what was calculated to be prudent limits; if there had been more data and time for experiment it would have been possible to go further in some aspects, while in others matters could have been approached differently.

Captain Weston's remarks about the need for duplication of the feed pump—and also those of Mr. Grout on the same matter—bore on the point that the results achieved were largely due to a consistent policy. It was true that a standby feed pump would, as it happened, have been a great comfort to those who operated the ships in action. But the point which must not be overlooked was that if, under difficult circumstances, any of the other important auxiliaries had failed, the results would have been equally unpleasant. There was only one boiler room fan, one oil fuel pump, one boiler circulating pump, one forced lubrication pump and so on.

It had not been suggested that any of these should have been duplicated. If the job had to be done again there was no doubt a feed pump would be fitted which would not draw attention to itself.

It would be realized, however, that if all the auxiliaries whose failure would have endangered the ship had been duplicated the weight target would have been greatly exceeded. The results obtained were partly due to a policy of "no duplication", and this required a high degree of reliability which was in fact obtained in nearly every case, and could be obtained in all.

The matter of obtaining increased endurance by the fitting of an auxiliary feed pump was examined at the time but to meet the original requirements for the vessels the weight of an additional pump did not appear to be justified. Compared to the pump actually fitted the weight and space requirements of a reciprocating pump, even if only capable of feeding the boiler at reduced powers, were considerable.

With regard to Captain Weston's remarks about the evaporator, the authors did not seek to imply that the evaporator was not to blame but all boiler experience went to show that the degree of salinity experienced in the boilers need not have caused corrosion, had the proper feed treatment been in use. This was confirmed in the steam gun boats.

Mr. Plumer and Com'r King raised the question of the water-cooled furnace. It was agreed that a mistake was made, and that it was made worse by the inadequate performance of the oil burning equipment originally fitted.

With this inadequate performance, it was unlikely that any change in boiler performance would occur when refractories were introduced to reduce the cold surface.

Notwithstanding the remarks of Com'r King, there was ample evidence of a reliable nature to show that a flame could be overcooled. In this particular case, the furnace rating was deduced from a trial of a three-drum boiler, during which it was claimed that a rating of $0{\cdot}373\times10^6$ B.Th.U. per cu. ft. per hour was reached. Only a small allowance was made for the fact that the furnace temperature was nearly 1,000 deg. F. less in the La Mont boiler. Subsequently it was realized that the assessment of the rating achieved during the three-drum boiler trial was unduly optimistic.

For a given combustion equipment in a confined space, the amount of cooling of the flame directly affected the specific volume of the combustion products and with a given mass input the time available for completion of combustion. If the rate of combustion varied directly as the temperature, this offset the inverse variation due to the specific volume, but carefully controlled scientific experiments had shown that this was only true over a limited range of temperatures; at high temperatures dissociation occurred, whilst below a critical temperature combustion was so retarded that it was virtually impossible to compete it.

Mr. Dunstan appeared to have been misled; there was practically no research work involved in the design of the machinery of these ships. Time alone would have prevented this, apart from lack of facilities. There was, however, considerable development and re-design.

Mr. Grout's view that there should have been heavy weather trials is undoubtedly correct; and it would, as it proved, have been worth a little delay in the ship becoming operational to carry out such trials.

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MEMBERSHIP ELECTIONS

Elected 14th February 1949

Members

Leonard Frederick Allen
Finn Sture Jonas Aspelin
Jan Frederik Beumer
William Hosea Brown
Archibald Dougall Bruce
Viggo Thorsten Bülow
Robert Chambers
Victor Bogvilo Cole, Com'r, U.S.N.
George Cunningham
Jim Fleming, Lt.-Com'r(E), R.N.
Edward Victor Hamer
John Howat Harbottle
Frank Harley, Lt.-Com'r(E), R.C.N.
Robert Linwood Ingledew
Knud Langkilde Jensen
Edgar Jack Johnston, Lt.(E), D.S.C., R.N.
Keith Elwyn Jones
Leo Ferdinand Klausen
Carl Henrik Kruhoffer
John Geoffrey Little, Com'r(E), O.B.E., R.N.
George Tindal MacDonald
Peter McKechnie
Andrew McKie
David Peters Maxwell
Edward Albert May, Lt.(E), R.N.
Henry Proud
Frederick William Purves, Lt.-Com'r(E), R.A.N.
David Ross
Lionel Taylor Sandiford
John Scholes
Herbert Brook Siggers
John Taylor Tooker, Lt.(E), R.N.
Leonard Alfred Whitefield, Lt.(E), R.N.
Thomas Godfrey Currie Wood, D.S.C.
Frank Edward Yeates, Eng'r Com'r, R.N.(ret)
Robert John Yorston

Associate Members

Robert Ferguson Hawkins
Alexander James Middleton
John George Alexander Robertson

Associates

Ausaf Ahmad
Thomas Charles Bishop
Sidney Ray Bond
Robert Grandfelt Brand
William Christie Cantes
John Edward Harris Chambers
Reginald Fred Fairbank
Noel Strafford Fowler

Alan Roy Malcolm
Alan Richard Morris
Alan Herbert Morton
Kenneth John Pover
John Edward Radcliffe
Carol Craig Richardson
Stanley Scott
Olle Scotting
Victor Ronald Welch
Boleslaw Stefan Witowski

Graduates

Alan Frederick Hodgkin
Ronald Gurney
James Stubbs

Student

Selçuk Somer

Transfer from Associate Member to Member

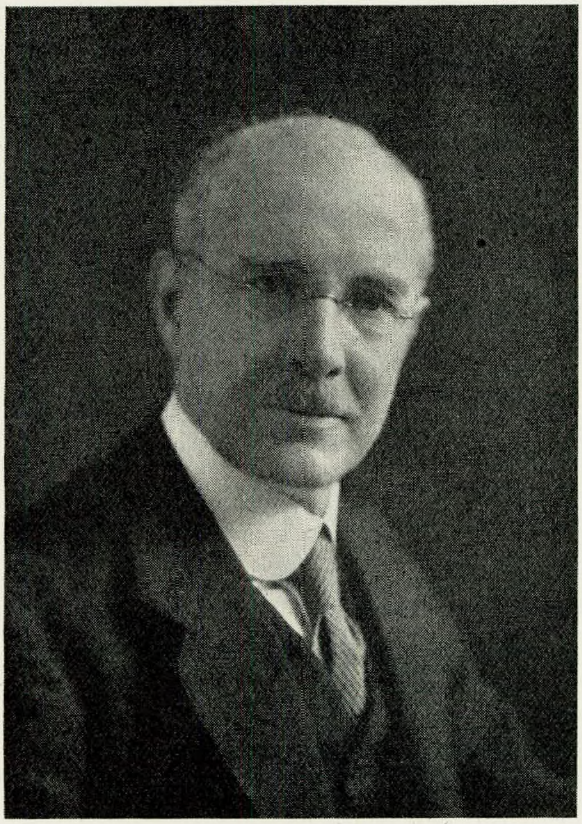
Dhruba Lal Neogy

Transfer from Associate to Member

Kenneth James Bateson
William Blowers
Roy Bradley
James Templeton Carson Brown
Raymond Crowther
Charles Dearden
John Fleming
Alexander Charles Girdler
George R. Lister
Norman Macleod
James Roland McCarlie
John McIntyre
James Morton
Robert Baxter Naismith
William Shearman
John Simpson
Reginald Smith
Leslie George Walley, A/Lt.-Com'r(E), R.N.
Richard Wanless
David Wilson

OBITUARY

Alexander Hanson Mather (Hon. Vice-President). The Institute has lost one of its oldest and most valued Members by the death of Mr. Alexander H. Mather, which occurred at Basingstoke on Friday, 17th December 1948 at the age of eighty.



He was born on the 8th March 1868 at Stratford, London and served his apprenticeship to engineering in the Stratford Locomotive Works of the Great Eastern Railway (later merged in the London and North Eastern Railway).

He went to sea is 1889 as 3rd engineer in the S.S. *Para* belonging to Messrs. Steel, Young and Co., of London and West Hartlepool and obtained his 2nd and 1st class Board of Trade certificates while serving with this company.

He next entered the service of the British India Steam Navigation Co., in 1894 and sailed in the steamers *Jumna, Golconda* and *Manora.* On two occasions during this period he was retained ashore to act as draughtsman and assistant to the late Mr. James Adamson, who was then the company's Superintendent Engineer at the Royal Albert Docks.

In 1896 Mr. Mather was engaged by Messrs. Caird and Rayner, Ltd., engineers, Limehouse, as draughtsman and was with them for over eight years in the drawing office and at the government dockyards in charge of the erection and official trials of the firm's fresh water distilling plant.

He was appointed in 1905 as engineer representative in London for the marine department of the Vacuum Oil Co., Ltd., and acted in this capacity for twenty-five years. During this time he was associated with the solution of problems of lubrication involved in the development of marine machinery following the introduction of the steam turbine and the internal combustion engine. In 1930 he was appointed chief engineer of the marine department of the company, and retired from business in 1933.

Mr. Mather was elected an Associate of the Institute in 1890 and Associate Member in 1892. He was elected a Member in 1893 and a Member of Council in 1900. In 1905 he was elected Honorary Treasurer of the Institute and he held this office until 1921. He also acted as Honorary Secretary of the City Premises Committee throughout the period of its activities in the collection of funds and the erection of the present premises in the Minories. He was elected Chairman of Council in 1927-8 and had been Vice-President since that time. He was a Life Member of the Guild of Benevolence from its foundation in 1934.

In addition to his business life, Mr. Mather was for many years actively and prominently associated with the Presbyterian Church at Barnet, whence he retired to live at Basingstoke earlier this year. His genial personality, his keen interest in his profession, and in particular his loyal co-operation in the work of the Council will long be remembered by his many friends and colleagues among the Institute Membership. He leaves a widow, a daughter and a son.

Magnus Arthurson (Member 7272) was born in 1880 and served his apprenticeship with Messrs. Dunlop and Bell of Liverpool from 1894 to 1900. He began his seagoing career with the Harrison Line in 1900. He became Assistant Superintendent Engineer with this company and in 1937 was appointed Chief Superintendent Engineer. He was elected a Member in 1933 and was also an Associate Member of The Institution of Naval Architects. In 1938-9 he was Chairman of the Liverpool Marine Engineers' and Naval Architects' Guild. He retired in May 1948 through ill-health after forty years' service with the Harrison Line. He had a stroke in July 1948 and died on the 7th January 1949. He was 69.

George Allen Broadbridge (Member 8543) was born in 1899 and educated at Emanuel School, London and served his apprenticeship with Messrs. Green and Silley Weir, Ltd. During the 1914-18 war he served as a cadet Flying Officer in the R.A.F. He served with the Port Line on S.S. *Port Lincoln* and *Port Hardy* and qualified as first engineer in 1925. He returned to Messrs. Green and Silley Weir, Ltd. in 1925 as estimating engineer. He was appointed Works Manager for this company at their Tilbury branch and during the 1939-45 war became Works Manager at the Royal Albert Docks branch. During the latter part of his career he was Assistant General Manager of Messrs. Silley Cox and Co., Ltd., at their Falmouth office. He was elected a Member in 1937. He died in the London Hospital on the 18th January 1949 while awaiting an operation. He was a bachelor.

Captain Robert Eves (Member 5119) for twenty years Chief Mechanical Engineer, Jahore Government, Malaya, is presumed to have died on or about the 13th February 1942, as a result of the sinking of H.M.S. *Giang Bee* by the Japanese in the Banka Straits.

Charles George Harris (Member 8360) was born in 1894 and acquired his early technical training at The Merchant Venturers College, Bristol. He joined the merchant service in 1914. In December he joined the *Middlesex* as 5th engineer and in December 1916 the *Northumberland* as 4th engineer. He accepted an appointment with the Nelson Line on several vessels on the South American service as 3rd, later as 2nd and finally as chief engineer in 1919. Leaving the Nelson Line in 1923 he joined the engineering staff of the Ocean Accident and Guarantee Corporation as an engineer surveyor for the Nottingham district and in 1932 was transferred to Bristol. He was elected a Member in 1937. He died on the 8th October 1948, at the age of 55. He leaves a widow.

John Lawson Gray (Member 8158) was born in 1891 and was educated at Jarrow Secondary School and served his apprenticeship with Palmers Engine Works of Jarrow. Beginning his seagoing career with the Hall Line he left to join the Anglo-Saxon Co. but returned to the drawing office of Palmers Engine Works in 1914. From 1918-22 he was employed by the Great Lakes Transportation Co., of Ontario and accepted shore appointments in Toronto and Montreal. In 1923 he joined the staff of British Tankers and served with this company for twenty-five years. He was appointed Chief Engineer of the M.V. *British Hope* in 1936. He was elected a Member in May 1936. He died in Colombo on the 16th September 1948 after a brief illness. He leaves a widow.

E. Frank Palmer (Associate Member 2860) was born in London in 1888 and served his apprenticeship there. From 1909-20 he was Assistant Master and Laboratory Demonstrator at the L.C.C. School of Engineering and Navigation at Poplar and in 1920 he became teacher of machine drawing, geometry and mechanics. After war service in the 1914-18 war, in which he was mentioned in despatches, he returned to teaching at Poplar. In 1940 he was promoted to the Paddington Technical Institute and taught strength of materials, applied mechanics and engineering. In 1948 he was Acting Head of the Mechanical Engineering Dept. He held a 2nd class Honours certificate in mechanical engineering with the City and Guilds of London Institute and was an Associate Member of the Institution of Mechanical Engineers. He was elected an Associate Member in 1913. He was part-author of "Modern Heating and Ventilation". He died suddenly at his home on 14th November 1948 leaving a widow and a son.

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JUNIOR SECTION

Lecture at Swansea

Mr. Calderwood gave an illustrated lecture on "Marine Diesel Engines" on 20th January 1949 at Swansea Municipal Technical College.

Mr. George Thompson (Vice-President), in introducing Mr. Calderwood, stressed the point that the main object was to interest students in the marine side of engineering, and to give them a broad view of the marine Diesel engine.

Mr. Calderwood in his lecture covered a period from the inception of the Diesel principle in 1905, the first use of the engine at sea in 1908, and then the sudden increase of these engines in the marine field from 1920 to the present day.

The construction of the engine was thoroughly described; the method of stiffening the casing and bedplates, and the means of taking up the propeller thrust. A section was shown of a piston top in relation to the cylinder head, and the position of where "hot-spots" occurred.

There were three or four types in common use at sea today, nearly all using the two stroke principle—some single and some of the opposed piston type. The method of connecting the top piston to the crank shaft was explained.

Another practical point explained was the method of withdrawing a connecting rod from the apparently complicated structure of the Diesel engine, and the positioning of the inspection covers. Cooling systems, oil and water, were explained and finally an illustration was shown of a Diesel engine of the future. This was a two crankshaft engine with a combined exhaust turbine, geared to one propeller shaft. The difficulties to be overcome were accessibility, and capability of overhaul without shore assistance.

Questions were asked after the lecture on types of fuel oil, filtering and cleaning oil on board, temperatures, scavenge blowers, and engine balancing. Mr. Thompson closed the proceedings at about 8.45 p.m. with a hearty vote of thanks to Mr. Calderwood, strongly supported by all.

Lecture at Falmouth

Mr. J. Paley Yorke gave a lecture entitled "The Importance of Scientific Training for the Young Marine Engineer" at Falmouth Technical Institute on 21st January 1949. The audience was not large but made up in enthusiasm what it lacked in numbers and was most appreciative. It was realized that this science was not only of vital importance but that it could also be good fun and good adventure too. Mr. Tirrell, the Principal, who was in the Chair, and his staff were most helpful and assisted in arranging various equipment needed to demonstrate experiments and the whole proceedings were much enjoyed by all. Mr. D. Dunn (Local Vice-President) represented the Council.

Lecture at Cardiff

A lecture entitled "The Combustion Turbine" was given by Mr. J. Calderwood, M.Sc., at Cardiff City Technical College on 2nd February 1949. The Chair was taken by Dr. Harvey, Principal of the Technical College, who was supported by Mr. Ivor J. Thomas, Vice-President, representing the Council and Mr. C. Moffatt, Chairman of the Cardiff and District Section. The audience was keenly attentive and the lecturer had a busy time coping with numerous questions relating to the lecture, which was much appreciated by all present. Mr. Church (Member) proposed and Mr. Ivor J. Thomas seconded a vote of thanks to Mr. Calderwood for his excellent lecture. In addressing the students, Mr. C. Moffatt briefly explained the purpose and functions of the Institute and concluded his remarks by thanking Dr. Harvey for his interest and kindness in providing facilities for the lecture.

Lecture at Gravesend

A lecture entitled "The Launching of Ships" was given by Mr. R. S. Hogg at Gravesend Technical Institute on 11th February 1949.

Mr. H. S. Humphreys (Member of Council) represented the Council and Mr. Etherington took the Chair. There were about eighty present and at the request of the Chairman, Mr. Humphreys took part in the discussion and proposed a vote of thanks to Mr. Hogg at the end of the meeting.

The lecture was most interesting and well illustrated, and the audience were held in close attention throughout. Considerable interest was shown with the American method of broadside launchings which Mr. Hogg demonstrated by means of a projector and some photographs taken from an American paper.

Lecture at Bristol

Mr. J. E. M. Payne gave a lecture entitled "Marine Engine Room Auxiliaries" at Merchant Venturer's Technical College, Bristol on 16th Febraruy 1949. There was a fair attendance but, at the same time, in view of the importance of the subject matter, it was somewhat disappointing. It had been hoped some of the students at the Bristol University, Faculty of Engineering, would have been present, but unfortunately this was not the case.

The Chair was taken by Mr. S. W. Partington, Vice-Principal of the Merchant Venturer's Technical College, who in his opening remarks dealt with the advantages and necessity of being a member of at least one of the various technical institutions, stressing the point that what one put into the institution concerned mattered more than what the individual got out of it.

Mr. Payne's lecture was listened to with attention, and great interest was shown in the various slides.

At the conclusion questions were asked for, and answered, by the lecturer, who later also showed to an interested few detail drawings of auxiliaries and engine room layout.

Lecture at Poplar

The Junior Section Lecture at the L.C.C. School of Engineering and Navigation was given this year by Mr. C. G. Crouch on the 17th February. The title of the lecture was "Steam Generation for Power Stations" and the Chair was taken by Mr. W. Laws, M.Sc., Principal of the School.

An audience of 170 consisting of marine engineers studying for their certificates of competency, evening class students attending the school and an unexpected influx of members of the Institute filled the lecture hall to capacity, additional seating accommodation having to be provided.

The Chairman in his opening remarks mentioned that these lectures under the auspices of the Junior Section of the Institute of Marine Engineers, which were poorly attended when held at the Institute, were now being given with great success in the Technical Schools all over the country. This session over 20 lectures were being given and the L.C.C. School of Engineering was proud of its part in originating and developing the scheme.

The lecturer, with the aid of a number of excellent slides, traced the development of the Babcock boiler during the last thirty years. Then a film entitled "Steam" showed in detail the construction of the various parts of a boiler and the erection of the boiler on site.

Mr. D. M. Reid (Member) stated that they all knew of the difficulty of acquiring practical knowledge in all the different branches of engineering, but the lecturer's description of the salient points on each slide followed by the film, had made that easy this evening and he proposed a hearty vote of thanks be accorded to Mr. Crouch, which was carried with acclamation.

A vote of thanks to the Chairman concluded the proceedings.

SYDNEY LOCAL SECTION

A dinner to welcome the President, Commander Sir Robert Micklem, C.B.E., R.N. (ret.) was held at Petty's Hotel, Sydney on the 18th January 1949, which was attended by sixty-two members and guests.

The official guests included Engineer Rear-Admiral A. B. Doyle, C.B.E., who had recently retired from The Royal Australian Navy, and whose last appointment was that of Third Naval Member; Capt.(E) E. A. Good, Engineer Manager, Garden Island; Mr. H. G. Conde, The Chairman of the Sydney Division of the Institution of Engineers Australian; Professor MacDonald, Professor of Mechanical Engineering at the University of Sydney; Mr. J. H. Hall, representing the Mechanical Engineers' Association of Australia.

All those attending the dinner were introduced to the President in an adjoining room where cocktails were served.

The toast of "The President" was proposed by Mr. H. A. Garnett, Local Vice-President for Sydney, and the President replied in a most interesting address after announcing the Council's official approval of the formation of the Sydney Local Section.

The toast of "The Guests" was proposed by Mr. H. G. Ferrier and responded to by Engineer Rear Admiral Doyle. The function was most successful and thanks are due to the Committee responsible for organizing it. The local Committee consists of: Hon. Secretary, Eng'r Capt. G. I. D. Hutcheson, R.A.N. (ret.); Hon. Treasurer, N. A. Grieves; Committee, Messrs. W. G. C. Butcher, E. L. Chounding, H. G. Ferrier, D. N. Finlay, F. W. Harper, F. J. Ward.

The following day a visit was paid to S.S. *Orcades* and about sixty members were received by the Chief Engineer and Ship's Officers.