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Small Screw Propellers.

BY MR. D. H. JACKSON (Member).

READ

Tuesday, February 2, 1915.

THE NEW PREMISES, MINORIES, TOWER HILL.

CHAIRMAN:—MR. ALEX. BOYLE (Vice-President).

DISCUSSION HELD

Tuesday, February 16, 1915.

CHAIRMAN: MR. GEO. ADAMS (Member of Council).

The CHAIRMAN: I feel it a great honour to take the chair at the first meeting on the reading of a paper in the new premises, and I should like, first of all, to congratulate all members of the Institute, old and new, on the acquisition of such a fine building. It is very gratifying indeed for us to possess such splendid premises as these, premises to which we can point with a just pride as being evidence of the importance of the Institute, and also as a proof of the great work done by the Institute, a work acknowledged and appreciated by the leading shipowners, ship builders, and engineers of the United Kingdom.

When I look round these splendid premises, I feel that they will become a centre and rallying point, a place of meeting for all members, and I am convinced as time goes on, that they will become more and more recognised as the headquarters of the Marine Engineers. We must all congratulate ourselves on the splendid work accomplished and the success we have already attained. I should also like to emphasise that we must not forget the work and labours of many of our members to whose efforts we mainly owe our success, those members who have so generously given of their own private time and of their voluntary labour to further the interests of the Institute. I should also like to refer to the ten who signed the application to the Board of Trade for the certificate of Incorporation, and so founded this Institute on a sound basis. Most of the signatories, for various reasons, have not been able to share in the proceedings for some years, five have died, three have retired from work, but two are still with us in active service. One is Mr. Jas. Adamson, and I must say this, that all through the 26 years of the existence of this Institute, his interest has never flagged; in fact he has given ungrudgingly, his spare evening hours to the work and the labours which he has given to the Institute have never ceased. I am sure that all the members will agree that we owe a deep debt of gratitude to Mr. Adamson. The other of the two is Mr. Leslie, who has given much valuable service to the Institute, and he, even more than most of the members, will be very pleased with these splendid new premises, because he has always strongly advocated that we should have premises in the City, and has taken an active share in the acquiring of them. The question of finance was always a difficult one when City premises came to be considered from time to time; however, a way was found a short time ago; a committee was formed, of which Mr. Leslie was chairman, and I think that the success that the committee has attained has exceeded our most sanguine hopes. The new premises are excellent, handsome and convenient. I look forward with confidence to the younger men taking up the work and carrying it on, and that they will keep the interests of the Institute at heart, as their predecessors have done, maintaining in every way the status of the marine engineer. The author of the paper is unable to be with us and has asked the Hon. Secretary to read it for him. I will now ask Mr. Adamson to do so.

THIS paper deals with the subject of Small Screw Propellers, purely as it affects the draughtsman or designer. The author has not touched upon any of the classic experiments, and the more or less abstruse theories deduced from them; but has endeavoured to treat the matter throughout from a fairly practical standpoint, as covered by his own experience. So far as the draughtsman is concerned, the first question to engage his mind on the subject of a propeller is:—

(*a*) How much room will the propeller occupy? If the diameter be proportioned on past experience, will the consequent shaft-line be convenient and practicable? This consideration is often of great importance when dealing with small propellers.

(*b*) Will the peripheral speed of the propeller be within safe limits?

These two points have usually to be settled in short time, and at short notice. Often, indeed, the diameter and pitch of propellers, and the exact position of shaft-line, have to be fixed at the time of tendering for an order; which is usually a very strenuous period.

This task being safely completed, the unfortunate and long-suffering draughtsman is granted a breathing space until the time arrives for:—

(*c*) The preparation of actual working drawings of the propeller.

There are pitfalls awaiting the unwary, even in this process. They are, however, not usually of a serious nature; and the author is bold enough to hope that certain of the notes contained in this paper may help to smooth the way of the draughtsman over some of these points.

Now, let us revert to the first consideration:—

(*a*) *How much room will a propeller take?*

Probably the great stand-by of the draughtsman in this matter is one or other of the well-known formulæ:—

(1) Diameter of propeller is proportional to

$$\sqrt[3]{\frac{\text{I.H.P.}}{\text{R.}}}$$ or else

(2) Diameter of propeller is proportional to

$$\sqrt[2]{\frac{\text{I.H.P.}}{\text{S3}}}$$

Where I.H.P. = indicated horse-power transmitted through *one* propeller.

R = revolutions per minute. S = speed of vessel, in knots.

Now, in spite of the careful experiments, deductions, etc., on which these two formulæ are based, the author is of the opinion that equally close results, together with greater handiness of calculation, may be obtained with the formula:—

(3) Diameter of propeller is proportional to

$$\sqrt[2]{\frac{\text{I.H.P.}}{\text{S.}}}$$

Obviously, such a formula only holds good for cases of close similarity, in form of vessel and speed. The Tables I. and II. annexed give some characteristic comparisons derived from the use of formula (3). Table I. shows a number of examples of small vessels of full body; displacements varying from 100 to 500 tons; speeds up to about 14 knots. Table II. shows a number of examples of vessels of from 700 to 1,000 tons displacement, and of high speed. Needless to say, where shaft horse-power and indicated horse-power are to be compared, the value of I.H.P. must be multiplied by a suitable coefficient (generally about 0·9) to obtain the corresponding S.H.P. For ships fitted with Diesel engines, this coefficient should be diminished to about 0·8 to 0·85.

TABLE I.

No.	I.H.P. through one Propeller.	Speed in Knots.	$\sqrt{\frac{\text{I.H.P.}}{\text{S.}}}$	Dia. of Propeller.	Dia. of Propeller. / $\sqrt{\frac{\text{I.H.P.}}{\text{S.}}}$
1	600	14	6·54	4·67 feet	0·71
2	400	10	6·33	4·75 ,,	0·75
3	600	10	7·75	6·00 ,,	0·775
4	600	10	7·75	5·90 ,,	0·76
5	800	14	7·56	6·00 ,,	0·795

In connection with Table I., it may be noted the propeller in example No. 1, ran at about 200 R.P.M., while that in No. 5 example ran at about 350 R.P.M.

TABLE II.

No.	S.H.P. through one Propeller.	Speed in Knots.	$\sqrt{\frac{S.H.P.}{S.}}$	Dia. of Propeller.	Dia. of Propeller. / $\sqrt{\frac{S.H.P.}{S.}}$
1	2,200	27	9·02	4·00 feet	0·443
2	4,960	28·2	13·3	5·54 ,,	0·417
3	8,250	30·6	16·4	6·75 ,,	0·41
4	12,250	32	19·6	7 67 ,,	0·39
5	8,670	33	16·2	7·00 ,,	0·432

It will be noticed that example No. 4 in Table II. shows a considerable discrepancy in the value of

$$\frac{\text{Dia. of propeller}}{\left(\sqrt{\frac{S.H.P.}{S.}}\right)}$$

That particular ship was of a bad form for the high speed at which she was driven. The propellers described in Table II. were all driven by steam turbines, at say, 600-650 R.P.M.

The above two tables will naturally suggest the construction of a curve in which the values of

$$\frac{\text{Dia. of propeller}}{\left(\sqrt{\frac{S.H.P.}{S.}}\right)}$$

are plotted against corresponding values of the block coefficients of displacement of the ships under consideration. Such a curve may readily be drawn by any draughtsman to suit the class of work with which he may be dealing. For obvious reasons the author is not at liberty to publish such a curve drawn from his own experience. It must be borne in mind, however, that with vessels of high speed, results calculated in this way upon the block coefficient of displacement, may be seriously upset by a bad design of hull; particularly where the after-body is of unsuitable form; as exemplified in Table II., No. 4.

Tip Clearance.—The question of diameter being settled, the next point, perhaps, is that of tip clearance. This must, without doubt, be greatly influenced by the peripheral speed at which the propeller is to run. For propellers running at very high speeds such as those fitted in turbine-driven vessels, it appears that the clearance between the propeller-circle and the ship's skin should not be less than about 18 inches; which figure might, when absolutely necessary, be reduced to 16 inches, although many designers stand out for not less than 24 inches of tip clearance for propellers of this class. The writer has in mind a vessel having tip clearance, between the propeller-circle and the ship's skin of 18 inches, with the propellers running at a peripheral speed of about 15,000 feet per minute. These particular propellers proved themselves remarkably efficient in every way, in spite of the high peripheral speed and relatively small clearance. There is no doubt that with turbine-driven vessels having three or four screws, a great loss of efficiency is caused by overlapping of the propeller-circles, as shown in Figure 1. This fault should be carefully avoided by the designer as far as possible.

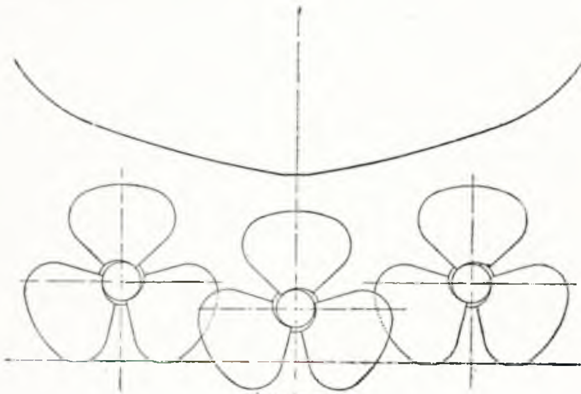

FIGURE I.

Turning now to propellers running at slower speeds, it is evident that the tip clearance may be greatly reduced. Probably the figure may be very much smaller where the point of minimum clearance occurs against the skin of the ship than where the propeller revolves in the ordinary type of stern-frame, as illustrated in Figure 2. This amounts to saying that twin-screws may have smaller clearance than single screws. The same point is borne out by usual practice in the construction of raised propeller steamers (in which, to secure a shallow draft the propeller works in a tunnel formed in the stern of the vessel). In many such steamers the tip clearance has not exceeded $1\frac{1}{2}$ inches, with peripheral speeds of some 3,000 feet per

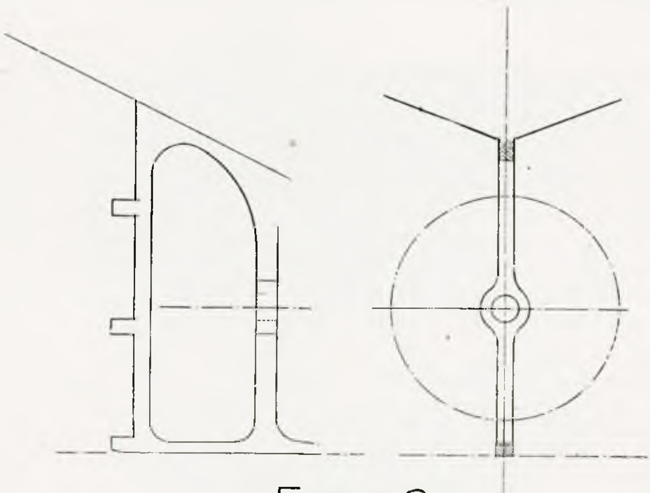

FIGURE 2.

minute. In connection with vessels of this class it is worth noticing that there appears to be no loss of efficiency caused by the propellers of twin-screw steamers turning inward, while the consequent improved accessibility of the engines (see Figure 3) is undoubtedly a great advantage.

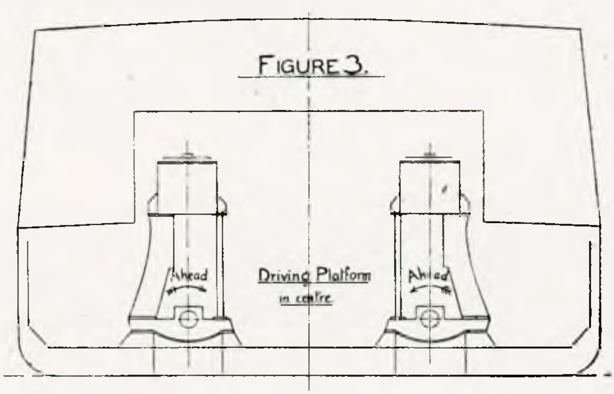

FIGURE 3.

Pitch.—On the subject of pitch of propellers little need be said: most designers have ample data, concerning slip upon which to base their calculations. Here it might be noted that the mistake is occasionally made of using a formula:—

$$\text{Pitch} = \frac{\text{Speed in knots} \times 101{\cdot}3 \times (100 + \text{percentage of slip})}{\text{revolutions per minute} \times 100.}$$

This should of course be written:—

$$(4)\quad \text{Pitch} = \frac{\text{Speed in knots} \times 101{\cdot}3 \times 100}{\text{revs. per min.} \times (100 - \text{percentage of slip}).}$$

The use of the wrong formula has the effect of reducing the result obtained, thereby probably making for an inefficient propeller. Some few engineers, in spite of the experimental research of the standard authorities on propellers, with the obvious deductions therefrom, are inclined to design propellers for very small slip: it seems to be well borne out that for small vessels of fairly fine form and of speeds ranging from 10-12 knots upward, slips may be as high as 20 per cent., or even in some cases 25 per cent, without necessarily indicating a lack of efficiency. It is certainly desirable that the ratio

$$\text{of } \frac{\text{pitch}}{\text{diameter}}$$

should be kept fairly high, which naturally involves increased slip, if the engines are to run at their full designed speed.

The preliminary figures of diameter and pitch having been settled, there remains:—

(c) The preparation of working drawings.

Blade Area.—Here the question of blade area becomes important. Now the blade areas of propellers for similar conditions may be compared by means of a formula analogous to that (No. 3) dealing with diameter of propeller circle as follows:—

$$(5)\quad \text{Blade area is proportional to} \sqrt{\frac{\text{H.P.}}{\text{S.}}}$$

In the writer's opinion the most desirable figure to compare in this way is what is known as the projected area of the blades. Another useful means of calculating the blade area required depends upon the thrust per unit surface of projected blade area. This figure may be as high as 12-14 pounds per square inch for vessels of high speed (say 25 knots and upward); while for quite small vessels (say 60 feet length or thereabout) of moderate speeds, the corresponding figure comes down to about three pounds per square inch. The curve (Figure 4) in which thrust per square inch is plotted against the speed of the vessel may serve to give some idea of the figures allowable.

Scantlings of Boss and Blades.—The next point to be considered is the axial length of the propeller boss. This often has to be settled before the actual working drawings of the propeller are prepared, because of its relation to the design of the tail-end shaft. It must be noted, in connection with the

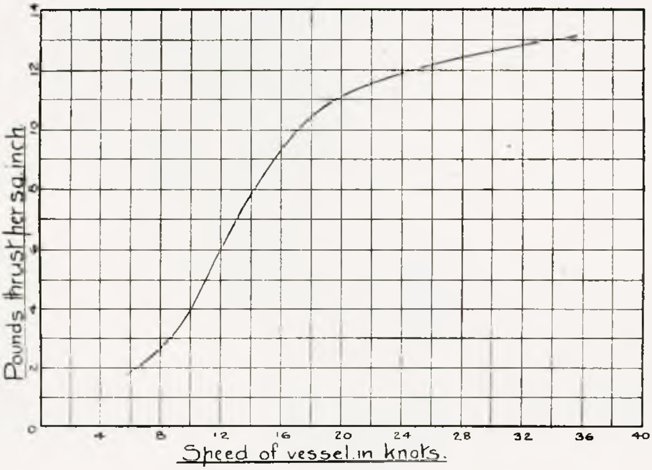

FIGURE 4.

following remarks, that the common practice with propellers of the size herein discussed—up to six or seven feet diameter—is to cast the blades solid with the boss. For propellers of normal form, such as would be fitted to vessels of moderate speed, the axial length of boss will be from $\frac{1}{8}$ to $\frac{1}{6}$ of the diameter of the propeller. The diameter of boss bears a close relationship to the thickness at root of blades, and must be considered in connection therewith. These two points will be dealt with later. The taper of the coned bore of propeller to suit the tail-end shaft, is commonly made 1″ diameter in 10″ length. A finer taper, viz., 1″ diameter in 12″ length is often used; there seems, however, to be no great advantage to be gained by this fine taper, while the difficulty of withdrawing the propeller is certainly increased, giving rise to the use of much bad language, for which the designer is, in part at least, responsible.

For obtaining the thickness at root of blades a number of formulæ are in common use:—

(6) T. $=\frac{1}{2}''$ per foot of dia. for cast iron, $\frac{3}{8}''$ for gun-metul, $\frac{5}{16}''$ for cast steel or bronze.

$$(7)\quad T_1. = \sqrt{\frac{d^3}{n \times b} \times K + C.} \quad \text{(Seaton.)}$$

$$(8)\quad T^2 = \frac{N \times I.H.P. \times (D - d_1.)}{B_1.} \left(\frac{d_1}{P \times S} + \frac{20}{R.D.}\right) \quad \text{(Barnaby)}$$

Probably the most reliable formula for all cases, is the Admiralty formula:—

$$(9)\quad M = \frac{B \times T^2 \times R \times P.}{I.H.P. \times (D - d_1.)}$$

T. = thickness of blade at surface of boss, in inches. T_1. = thickness of blade at centre of shaft, in inches; see Fig. 5 (*a*). d. = dia. of tail-end shaft, in inches. d_1. = dia. of boss, in inches. D. = dia. of propeller, in feet. n. = number of blades in one propeller. b. = breadth of blade at root, in inches, measured parallel to shaft (see Fig. 5 (*b*)). B. = breadth of blade at root, in inches, measured as in Fig. 5, (*c*). B_1. = breadth of blade at root, in inches, measured as in Fig 5. (*d*). R. = revolutions per minute. P. = pitch of propeller, in feet. I.H.P. = indicated horse power transmitted *through one blade*. S. = speed of vessel in knots. C. $=\frac{1}{4}''$, K. = 1·5, N. = 2·0; (all for manganese-bronze).

Now M, the constant in the Admiralty formula, has for an ordinary manganese-bronze propeller, a value of from 90 to 120, according to circumstances, with proportional values for cast-iron or cast steel. A propeller was recently designed to work in rough broken water, where whirlpools, rapids, small branches of trees, and other unpleasant incidents were commonly to be met with. For this purpose the constant M for a propeller 6′ diameter, 6′ 6″ pitch, of manganese-bronze, was made equal to 130. This propeller has given satisfaction in service, and up to the present still has its full complement of blades.

In order that a sound casting may be obtained, it is of the utmost importance that the thickness of metal at the boss should be carefully proportioned to suit that at the root of the blade: Figure 5 (*a*), shows proportions which give good results. The thickness of metal in the boss should not be less than that shown, but may be more if desired: A should, however, be greater than B, and B should be greater than C. The Founders generally prefer, especially in bronze propellers, that the propeller should be cast without the recess indicated at D, this recess being afterwards machined out when the pro-

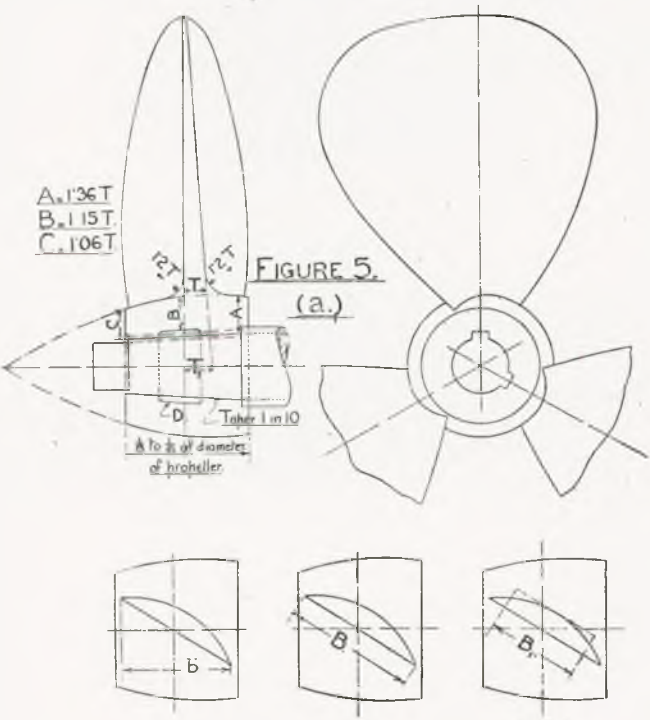

FIGURE 5.
(a.)

(b.) (c.) (d.)

peller is bored. Such a preference may possibly be due to the practice of charging for castings by weight. In any case, the axial length of the recess should not exceed about $\frac{1}{3}$ of the length of the boss. Two keys must be fitted, and it is an advantage to arrange each keyway in the propeller to come opposite to the root of a blade. Hence a four-bladed propeller will have two keys placed 90° apart, while those in a three-bladed propeller will be arranged 120° apart. See also Figure 5. It may be noted that the crushing load on the side of the keys has been allowed as follows, with satisfactory results:—

Crushing load on side of key in shaft: 22,000 lbs./□″	Assuming one key to transmit $\frac{2}{3}$ of total torque.
Crushing load on side of key in propeller: 18,000 lbs./□″	

These are, however, high values, and must certainly not be exceeded. The thickness at the tip of the blades of an ordinary manganese-bronze propeller need not exceed $\frac{3}{8}''$ for a propeller 6′ in diameter, while for a high-speed propeller of that size, with good tip-clearance, it may be $\frac{1}{4}''$ with perfect safety.

Shape of Blade.—Much has been written; many ingenious theories have been advanced; and many equally ingenious designs have been registered and patented; all dealing with the shape of propeller-blades. And, speaking very broadly, not one of these ingenious designs is any better than its fellows; and not one shows any real superiority over the simple blade-form which is commonly adopted. General experience and practice lead one to the conclusion that for propellers of moderate speed, the type of blade-form shown in Figure 6, at (*a*) gives good results. It is probably

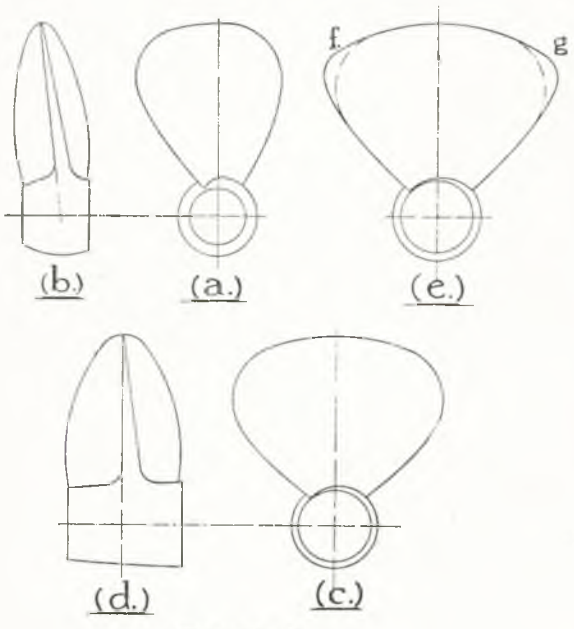

FIGURE 6.

also an advantage for the blade to be set back as shown at (*b*), instead of normal to the shaft centre-line. Fast-running propellers, as fitted to turbine-driven vessels of fairly high speed, give good results when made with a perfectly symmetrical blade-form, normal to the shaft centre-line; as indicated in Figure 6 at (*c*) and (*d*). In propellers of the latter class, where very wide blades are common, it is well to avoid blades of the form shown at (*e*) in Figure 6. Such a blade-form does not give good results—probably, because the mechanical weakness of the corners of the blade indicated at (*f*) and (*g*) causes deformation of the blade under working conditions. A propeller having blades of that form might possibly be improved by the removal of these corners, in spite of the reduction of area entailed.

Projection of Propeller-Blades.—With regard to the actual projection of propeller blades, the following method was evolved by the writer, for his own use. It differs from most methods commonly employed in that it gives an absolutely correct projection of the propeller; and also gives a correct value for the developed area. Especially with the very wide forms of blade common in propellers for turbine-driven vessels, of high speed, the inaccuracies involved with the usual methods of projection are sometimes of some consequence. Referring to Figure 7, the section of boss and blade is drawn from figures obtained in the manner previously described, under the heading, "Scantling of Boss and Blades." The projected blade is next drawn, to give the required area and blade-form. This projected area should be reckoned on that part of the blade outside the circle AB; the distance CD being made equal to $\frac{1}{3}$ of the radius Z. The line FG. is drawn parallel to the working surface of the blade, in the usual manner; the distance EF being equal to $\frac{\text{Pitch of propeller}}{2\pi}$. The length of arc HK (which is drawn about the centre of propeller, L) is measured along the line FG, from F, giving the point M. This is readily done by means of a flexible steel scale, a flexible batten, or other similar means. The point M is projected back on to the pitch line, NE, corresponding to the arc HK, giving the point O. The point O is projected perpendicular to EF, to meet the projector drawn from H, parallel to EF, in the point P. Then P is the side elevation of the point H at the edge of the propeller blade. The length OE is the actual length of the helical arc, HK, on the surface of the blade. Transferred to KQ, this length gives a half developed-section of the blade, at the radius LK; KR being equal to ST. A circular arc, KU. is drawn about the centre X; the distance LX being equal to about $\frac{1}{10}$ of the diameter of the propeller. This same point, X, is the centre for all corresponding arcs; *e.g.* WV. Now

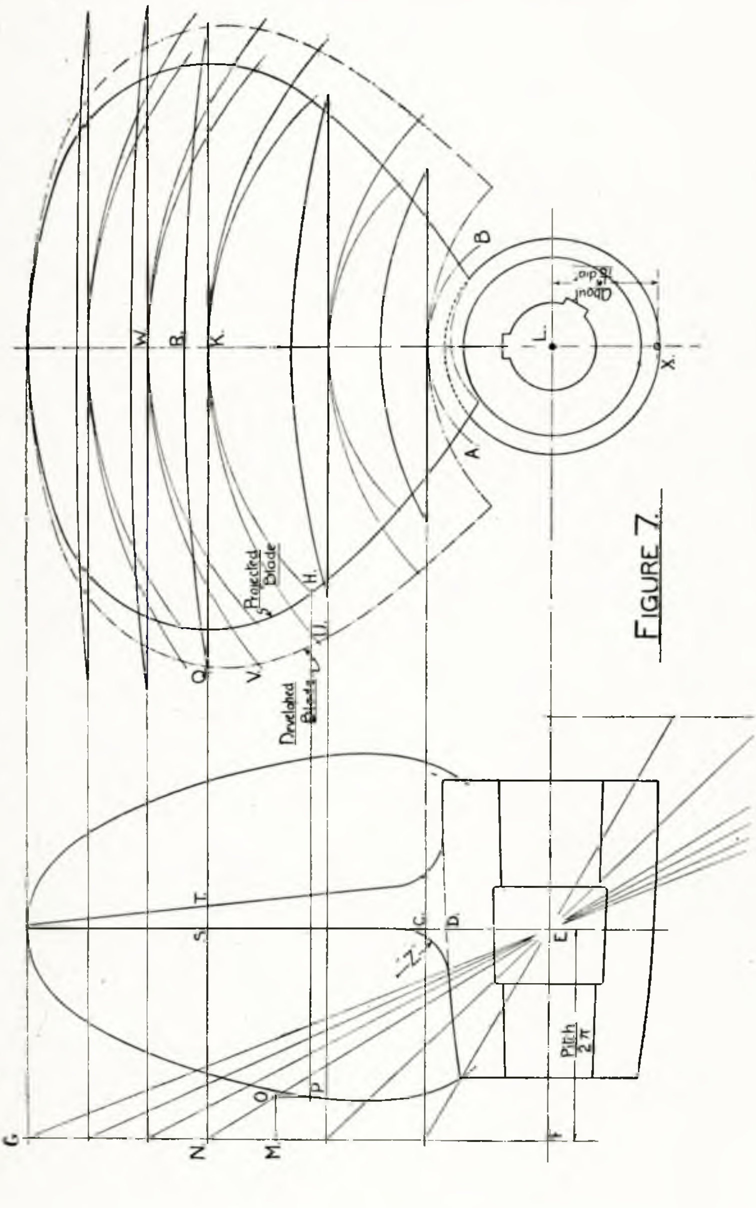

FIGURE 7.

if the straight-line length, OE, be transferred to the circular arc, KU., measuring from K. to U., then U is the corresponding point to H on the developed or expanded blade. This process being repeated, the side elevation, and developed view of the blade are obtained as shown. The side elevation is a correct projection of the blade, and the development of the blade gives the correct developed area, together with a good approximation to the shape. It is of course impossible correctly to develop the shape of a propeller blade on to a flat surface. The foregoing method of projection may readily be adapted to deal with propellers having either set-back blades, or blades of increasing pitch. The methods of adaptation will be obvious to anyone accustomed to the design of propellers.

The writer makes bold to hope that these notes on propeller design may have touched upon some points which are not as a rule made clear in text-books, but which are of real interest to the propeller-draughtsman.

In conclusion, the writer's thanks are due to Mr. H. E. Yarrow, for permission to publish certain of the foregoing notes.

———o———

Mr. Wm. McLaren: It is difficult to discuss this paper at once as it is on a subject which has to be carefully studied, and is also well worthy of our careful attention. The propeller draughtsman has no doubt some troubles to negotiate, and in some cases he has little bits to take off or to put on before the design is approved, and the whole completed. Within the last nine months it has been impressed on me most strongly that the driving side of a propeller should be polished like a burnished pan, as I have observed with regard to spirals which are used in connection with some machines under my observation, that the efficiency is taken from these spirals by a little dust, and it is simply by the pitch that the motion is given. From time to time when dust gathers on them, they are wiped with a cloth to maintain the efficiency, and here is seen the analogy to the driving side of a propeller blade; it ought to be kept as smooth and clean as possible.

Mr. R. P. Logan: I am very pleased to have heard Mr. Jackson's paper read. There are one or two points I would like to remark on. One is, the two keys in the boss—why two keys, and what is the advantage gained, with a good fitting boss? A taper, say $\frac{3}{4}$in. to the foot with one good fitting key will never give any trouble. Another point mentioned by the last speaker

(Mr. McLaren) was the smooth face of the ahead side of a propeller blade. He gives an instance where a coat of dust will retard its progress quite perceptibly. In the early days of the bronze blades the filing and burnishing was quite a job in the shops. In some cases after all this work, after a voyage, they were coated with paint in dry dock. On one occasion having raised the point with the superintendent, his idea was that it was an insulation, and saved zinc plates on the rudder post and corrosion. I had an opportunity in my own experience of putting this to the test. In an outport, getting the ship in dry dock, I took advantage to thoroughly scour the propeller blades with sandstone. The smart run home convinced me that the clean and smooth surface as stated by the last speaker had all to do with it. All through, the paper is a draughtsman's paper, as such, it lends itself to a good discussion, owing to diversity of opinion in designing the propeller or shape of blades and you can take a bit off here and put on there. As there are many points well worth perusing, I must thank the author for his paper.

Mr. W. E. Farenden: I regret that I have had but little experience with small screw propellers running at high speeds, but for a propeller to give the best results it is essential that the diameter, pitch and blade surface should bear a correct proportion to each other for the I.H.P. of the engines.

One great feature for the highest efficiency is a favourable position of the propellers for allowing the freest access of water to them, another is that the screws should be well immersed, and when this is the case they are much steadier in operation.

Mr. Jackson refers to results being seriously upset by a bad design of hull, particularly where the after-body is of unsuitable form. This is quite true, and although the propellers may be identical in vessels of similar dimensions and I.H.P., the results from the vessel with the unsuitable after-body will not be so economical or satisfactory, showing that it is not always the propeller that is at fault, or the Engineer.

I quite agree with Mr. Jackson that overlapping of the propeller circles should be avoided, if possible, as this causes a loss of efficiency. Mr. Jackson refers to vessels of fairly fine form that the apparent slip may be as high as 20 to 25 per cent. without indicating a loss of efficiency. Would he consider that in the case of vessels of 12,000 to 15,000 tons and of fairly high speed, with reciprocating engines, this amount of slip would give as high efficiency as those with propellers giving a slip of 8 to 10 per cent.

Mr. E. W. Ross: As the author states in his opening remarks, this paper deals with the propeller from a draughtsman's point of view, and with small propellers only, suitable for small vessels, but we, as Marine Engineers, as a rule, have to deal with something of much larger dimensions. Many theories have been put forward as to the shape of propeller blades, but it appears to me that it is a question of trial and error, and that ship and engine builders get their data from known experience from previous ships, and is very often a question of cutting away or adding to the contour of the blade as fancy or experience dictates. I have in my mind one ship built by builders of repute, where the general shape, contour, and lie back of the blades were altered several times before a propeller suitable to the ship was evolved. The question of pitch to suit the special runs of the ship's hull is also, I believe, one of experience more than theory, and I should be pleased to know the author's opinion as to variable or true pitched propellers. Some we find of true pitch from root to tip, others increasing towards tip, while others diminish towards that point. The author mentions that two keys must be fitted to each propeller, but on that point I must decidedly differ from him, as I hold that one key, well and truly fitted, is better and more reliable than two keys, which theoretically should also be likewise well fitted, but I leave my practical friends to see the difficulties in that direction, as it has been mine to go through that experience.

The question of taper to the shaft cone is important, and if the propeller is well and truly fitted to the shaft and secured with the nut, it is supposed to be sufficient to drive without a key, but I will not say that I would have the courage to try the experiment without one.

I am afraid I am wandering from the subject of the paper, but our Chairman remarked that we were not tied down to that, and I would mention one point that I have often drawn attention to, but is never remedied by engine builders or apparently asked for by superintendent engineers or recognised authorities, that is, the thickness of the coupling on propeller shafts which I say is nearly always inadequate for that time of the ship's life, which comes in the periodic survey and examination. The propeller has to be started from the shaft, and resistance to that can only be made at one point—the shaft coupling, which not being made of sufficient resisting thickness is liable to and has been known to be distorted. I have never seen a computation made of the hundreds of tons required to start a propeller off the shafts of our ocean liners, but I say, is it fair that shaft couplings should be subjected to these great strains when adequate provision has not been made to withstand them.

Our engine builders will tell us their provision is sufficient for driving purposes, but provision should be made for all conditions—and one condition is—that shafts be periodically inspected, which necessitates the drawing of the shaft; all due care is taken in that event, but care will not always circumvent inherent weakness which could have been obviated, and I would suggest that another one-third to one-half thickness of coupling should be added to all propeller shaft couplings. I think we ought to thank Mr. Jackson for a very interesting and instructive paper. There are many formulæ instructive to the theoretic mind in it, but for all that the authorities have said or written, there is apparently much yet to be found out about screw propellers.

Mr. R. Balfour: This important paper has just been handed consequently there has not been much opportunity for its perusal. Mr. Logan has referred to the method suggested as to the fitting of propeller bosses on the shafts, and I quite agree with his remarks.

Under the heading of scantlings of boss and blade the author deals with the taper of the coned bore of the propeller to suit the shaft, and considers that a taper of 1 in. diameter in 12 ins. is too fine. I have a very vivid recollection of three cases which came under my notice where the taper was $\frac{3}{8}$ in. in 12 ins., needless to say these gave endless trouble. I attributed this to a clerical error in the drawing office; $\frac{7}{8}$ in. in 12 ins. is considered good practice in ordinary. The author refers to the soundness of castings, this of course, depends greatly upon the cast, design, method of casting and amount of surplus metal in the header.

In Fig. 5 (*a*) the design at the root of the blade the radius is given as 1·2T on each side. I don't think this is good practice, as abrupt termination of any structure should not be encouraged, a difference of radii gives a diagonal termination, consequently stronger section. As to the security of the boss on the shaft the author states that two keys *must* be fitted. I am of opinion that one key is sufficient as the other robs the boss of its surface grip on the cone apart from the difficulty in fitting the boss with two keys.

I congratulate the author on his useful paper, the subject is a very appropriate one, and our thanks are due to Messrs.

Yarrow for allowing him to give us such valuable information; and I am sure that we all delight to have Mr. Boyle in the chair on this auspicious occasion.

Mr. B. P. Fielden: I agree that the taper of the propeller cone should not be too fine, and think that $\frac{3}{4}$in. per foot is a very fair standard.

I remember having a similar experience to that which Mr. Balfour referred to where the taper was $\frac{1}{2}$in. per foot, and that although the shaft was properly fitted in the first place, when it was removed for examination later it was found that the propeller had worked itself up on to the cone of the shaft. The shaft was again refitted, and run for a further term of two years. It was again found that it had worked itself forward, and the shaft and boss were therefore renewed with another pair where the taper was $\frac{3}{4}$in. to the foot, and since then no trouble has been experienced.

The author of the paper has not gone fully into the subject of the pitch, and I should be pleased if he would give his views on True *v.* Differential Pitch Propellers. It is my opinion that the differential has an advantage over the true pitch.

In regard to the thickness of the blade, while a formula is very useful for determining the thickness, I think that this should vary according to the trade upon which the vessel is engaged, as for instance, a vessel trading across the Western Ocean where the passage is frequently made under very light conditions and consequently with very heavy racing of the engines requires considerations of its own.

I agree with the previous speakers that one key in propellers is preferable to two for the reason that it is very difficult to fit two propeller keys so that each of them take its share of the load.

The meeting closed with votes of thanks to the author of the paper and the Chairman. The discussion was adjourned till February 16th, by which date it was hoped that Mr. Jackson might be able to reply to various points raised in the course of this evening.

Extraordinary General Meeting.

Tuesday, February, 16, 1915.

CHAIRMAN: MR. GEORGE ADAMS (Vice-Chairman of Council).

BEFORE we proceed to the business of the evening, it is my painful duty to refer to the death of Mr. Joseph Hallett, who was for over four years Chairman of Council. Although for a short time past his health had not been good, a week ago he was in the City transacting business as usual, but early on Tuesday morning he was taken with heart seizure, from which he did not rally. It is a very very sudden blow to his family, and while a letter of condolence and sympathy has been sent by Mr. Adamson on behalf of the Institute, I feel sure that you will agree that it is fitting to make reference to the loss we have sustained. Mr. Hallett took a keen interest in the work of our Institute, and did everything in his power to further its concerns, especially in regard to the scheme for the new building. His business relationship and his connection brought him into touch with a large number of influential engineers, shipbuilders, and shipowners to whom he was in a position to represent the interests of the Institute, and was able to gather valuable subscriptions. His loss to the Institute is very great, as he not only gave his personal attention but made the Institute a hobby, and when a man has a hobby, personal time is not reckoned in value. The time and trouble Mr. Hallett put into this work was considerable, and when we recall the number of meetings he attended and the consideration he gave to the details for this building we give him all credit. Nevertheless, by the goodness of the great Engineer of the Universe, Mr. Hallett was permitted to see the end of his work, as far as the erection of this building was concerned, and then was called away to higher work. We Marine Engineers must do our utmost to maintain the high ideals this building is meant to convey to the general public. As you know, the Lord Mayor of London laid the foundation stone of this building, and we considered it a very high honour, and one which we probably did not anticipate when the scheme was originally framed. We must remember that our Institute is for the scientific side of engineering, and it is mainly on these lines that it was founded and has been maintained, let us therefore do all in our power to cultivate these aspirations and appeal to all our members to lend their aid.

The HON. SECRETARY: I am quite sure that we are all in very deep sympathy with what Mr. Adams has just put before us. Personally, I feel very much the loss of Mr. Hallett, with whom I was very closely associated, especially towards the close of the work connected with the new building, and I now feel great regret that such an excellent worker has been called away, it will be hard to find someone to take his place and carry on the work in the same enthusiastic spirit. I wrote to Mrs. Hallett expressing our sympathy with her in this great grief which has overtaken her, and I am quite sure that the expression of our sympathy will be joined in by everyone who knew Mr. Hallett, and the good work which he did in connection with the Institute.

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The Extraordinary General Meeting called for to-night is now open for the purpose of re-confirming the following resolution:—

> "The time has now come in view of the increasing membership of the Institute of Marine Engineers to make application to the Board of Trade for power to increase our membership to 2,000, and I propose that steps be taken to carry this into effect."

I proposed this resolution at a meeting on the 20th January, and it was seconded by Mr. A. H. Mather. For the information of members who were not present when this matter was brought forward, I may mention that it is necessary to apply to the Board of Trade for powers to increase the membership, and to pay a fee in accordance with the increase.

The resolution was put to the meeting and agreed to.

The CHAIRMAN: It has been proposed, seconded and agreed that this resolution be presented to the Board of Trade in the usual form and the necessary fees paid. The details are left with the Hon. Secretary to deal with.

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The CHAIRMAN: We will now proceed to the discussion of the paper on "Small Screw Propellers," which was read on February 2nd. The Author has sent some remarks in reply to the discussion held, these will be put before us by Mr. Adamson.

Mr. JACKSON writes as follows:—I agree most strongly with Mr. McLaren that the driving faces of a propeller should be kept as smooth and clean as possible. In fact, if it were practicable I would have the whole of the propeller—both faces of the blades—burnished, as quite a large proportion of power is absorbed by a rough surface. I think it is also well established that a perfectly smooth polished surface to the blades is of no small value in resisting corrosion.

Mr. Logan and others remark on the difficulty of fitting two keys to a propeller. I must say that I rather anticipated a general disagreement with what I said on this point. I advocate the fitting of two keys to propellers of the class under discussion for one reason, because there is always a tendency for a mechanic, when fitting a key, to make it bear on the top rather than on the sides. This, if only one key be fitted, rather invites a certain tendency of the propeller to "rock" on the shaft. This may, with a high-speed propeller, cause serious trouble. Another, though less frequent reason, is that in propellers for high-speed vessels where scantlings of shafting, etc., are sometimes cut down to a very fine point, the fitting of only one key (of proportionately larger size) would involve an increase in the diameter of shaft and propeller boss. This will no doubt seem rather a far-fetched point to engineers accustomed to big ships, and Lloyd's scantlings. I have in mind, however, more than one case, where the size of shafting was actually increased for this reason. I have spoken to several mechanics, skilled men of long experience, concerning the fitting of two keys in a propeller. I find that they seem to consider it a thoroughly practicable job, though of course it is not as simple as fitting one key. I may mention that in naval work of this class it is standard practice, almost invariably, to fit two keys.

Concerning the design at the root of the blade (Fig. 5A), Mr. Balfour suggests that the radii at the root should be unequal—the larger radius forward and the smaller radius aft. Now it must be remembered that the drive is transmitted approximately equally from both the forward and after ends of the boss; consequently the radii at the root of the blade should be about equal, so far as the drive is concerned. Regarding the blade as a cantilever, subject to an ahead thrust, it would certainly seem that a larger radius forward would be desirable. I have noticed, however, that two or three firms which specialise in the casting and finishing of propellers, adopt and recommend equal radii on the forward and after sides of the blade.

Dealing with pitch, and percentage of slip, I mentioned 25 per cent. as not being an excessive slip in some circumstances. However, with propellers running at moderate revolutions, as in the case mentioned by Mr. Farenden, I should not like to see as high a figure as that. In the case cited a ship of 12,000 to 15,000 tons, of fairly high speed, with reciprocating engines, I should say that a slip of 12 to 15 per cent. would be consistent with efficient working of the propellers. At the same time I must admit that ships of that size are rather out of my province.

Both Messrs. Fielden and Ross mention variable or differential pitched propellers. Now, for turbine-driven propellers, running at high speeds, there seems to be practically no evidence in their favour. For more moderate revolutions, such as obtain with the average ship driven by reciprocating engines, there is certainly more to be said for an increasing pitch, although I do not think it has ever been conclusively proved that a true-pitched propeller cannot be made to give the same results as those of an increasing-pitch propeller. What often happens is something like this: a true-pitch propeller, of a certain pitch, gives indifferent results on trial, so the owners or builders decide to try a propeller of increasing pitch. This propeller is made with its initial pitch equal to that of the original one, and its final pitch considerably greater. When it is found that an increase of perhaps half-a-knot is obtained, naturally the experiments are finished with, and up goes the reputation of increasing or variable pitch! I certainly do not think that the pitch should be varied from root to tip of the blades, although I believe that this has been claimed to reduce cavitation and pitting. To my mind, such a variation is extremely likely to cause eddying and inefficiency. Of course, in practice it is difficult to get a propeller of the true designed pitch from root to tip, but as a rule bronze propellers do not vary to any serious extent. Also the actual working pitch is apt to be an uncertain quantity, without a good stiff design of blade; as a weak blade becomes distorted under the thrust of water.

A ship recently under survey in Glasgow, when fitted with bronze propellers, produced a distinct musical note at certain speeds, the source of the sound apparently being the propellers. In the words of one of her engineers, "She used to sing like a canary." When cast-steel propellers were fitted, although they were rough, ugly looking things, yet the noise stopped, and speed increased slightly. I believe this was entirely due to weakness and consequent deformation of the bronze blades, and the superior stiffness of the steel blades.

Mr. F. M. Timpson: We are glad to have Mr. Jackson's views on the discussion of February 2nd, but I do not think that we will all agree with his views of keying the boss, which are averse to usual teaching. The author gives a few sketches illustrating shapes of blades; these may be greatly added to by other designs. At one time I was engaged on trials of various shapes, and a blade which had a bend at the tip was brought out with the object of throwing off a more solid body of water. Taking a number of trials with the smaller vessels an advantage of about $\frac{1}{4}$ knot over straight bladed propellers was got, which seemed to prove that an improvement might be got from the bend. There is no doubt a great deal of controversy about propellers, in fact it may be termed a never ending one.

The Chairman: There are many small points on which members may be at variance with the writer of the paper, and we should be very glad to hear their views and have a good talk on this subject.

Mr. J. Thom: As has already been mentioned, Mr. Jackson's paper has been written principally with regard to small-sized screw propellers, and not to larger, therefore the fitting of the propeller to the shaft has to be more perfectly done than is quite necessary with a larger propeller. In speaking of fitting two articles together you use a millimetre guage and say, well, if it is fitted to the ten-thousandth part of an inch it will be a good fit; with the propellers spoken of here, if they were fitted a little finer even than that, there is no need for two or any number of keys to keep it in its place, there is only room for one, and that one may be less than half of the standard key that is used. If two keys are necessary, then the machines that did the work are of very inferior quality, or the men were not using them to the best of their ability. If the lathes and tools are equal to the work there should be no difficulty in making a small shaft propeller and boss to fit quite easily, but a second and a third cut must be taken, and a very fine cut to finish. It is with the working tools that the good job is got, independent of the number of keys. A key is only fitted to prevent revolving. The boss should fit so tight on the shaft that it is not necessary to put any pressure on the top of the key, only on the sides, and such will be a perfect job and will give no difficulty afterwards. Referring to larger propellers and shafts, these points are magnified, not only as regards fitting, but quality of material. Suppose a steel boss to weigh a ton, if the casting is sound, there is probably as much material left from the cast as in the article cast, that is, if the boss weighed a ton, there was a ton on the top of it, and the man who sold the material had to cast two tons and had to charge two tons for it. But he does not always get the chance of doing that, as the seller does not explain the loss, or he thinks the purchaser ought to know. In very many cases he does not, hence the difficulty in getting a perfectly sound casting at the price. A steel boss is obviously a very difficult casting to make on account of the difficulty to get the metal to run into all the sections. If the pattern has not been perfectly arranged there will be harder and softer parts of the metal, and to prevent it being wasted it may be machined out as near the size as possible with ordinary tools, and to finish it properly the grinding tool is used—which takes a particle equal to the hundred-thousandth part of an inch—this makes it perfectly true. The shaft can be dealt with more readily to secure a good fit throughout with a clean surface, still, a mistake may be made as regards the distance the propeller should go on, and thus lead to trouble in fitting. To prove a good fit between the shaft and boss, in the place of the usual marking, take a lighted paraffin wax candle and allow it to burn near the shaft, smoking it all over the tapered end till it is just slightly black. The thickness of that smoke is about ·0000001 inch, therefore it will not perceptibly affect the distance the boss goes on to the shaft; it will simply show where the bearing is, and if this is not satisfactory then it must be machined.

With reference to the radii on the front and back of the blades, there is no reason why they should be the same. The reason why the radii should not be the same back as front is, that when you make a casting, if one radius is exactly opposite another that will be the weakest part; if one radius differs from the other it will increase the strength of a casting, whether the material be steel, iron or bronze.

Mr. J. G. Wells: The detail of keys has attracted much attention, the well established practice of employing one key has been contrasted with the more recent idea of fitting two or even three when requiring a perfectly secure adjustment. The author's practice is evidently with high speeds of revolution, and doubtless the difficulties due to vibrations are urgent, and the security of each part is a matter of the utmost importance. There is no question but that a single key does not give so great security against possible movement as two or three. Two keys will give a powerful drive, but with two only there is a risk that the centre of mass will not be in the axis of rotation and thus give rise to vibrations due to the want of balance. These points only arise when the speeds of rotation are high, and is one of the results of the adoption of the steam turbine.

It is difficult to comment upon the author's rules and data, for they are evidently based upon special experience which is not in the possession of the general engineer. Such special knowledge has a commercial value, and the Institution is fortunate in being able to include this data in its proceedings, but whilst recognising this, it is difficult not to ask for a more complete treatment of the subject at the author's hands, for he could evidently add much valuable matter if he felt himself free to do so.

It is generally recognised that the theory (that is a rational explanation) of the action of the screw propeller has yet to be formulated. It is difficult on account of the large number of factors that have to be taken into account, each of which mutually react, so that their individaul effects can only be separated in a few cases of the simplest character. Probably much may be learned from the action of turbines and centrifugal pumps, when thinking out the action of a propeller. The great difference that must be allowed for is that in the case of a propeller there is no assistance to be obtained from the casing in directing the flow of the water in the best way towards the screw, and to reduce the lost work to a minimum by giving the best direction to the stream leaving the propeller. These considerations have led designers to the use of guide blades and to enclose the propeller in a short tube. From the necessity to reduce loss of energy, turbine designers carefully consider the angles of entry and exit of the vanes so that the shock of entry may be a minimum, but such a result can only be obtained for one set of conditions of speeds of revolution. In the case of a propeller to obtain this result is extremely difficult, because of the disturbing effects upon the flow of the water towards the screw by the ships skin whose contour and distance from the screw is probably different in every case that the designer has to consider. Another point of moment is the centrifugal effect due to rotation, whilst there is the relative value of the propulsive effect that can be obtained from the different parts of the blade from the boss outwards to the tips of the blades. Since in any actual case all these factors co-operate in very different degrees, it is not surprising that in practice almost every marine engineer has his own ideas of what constitutes the real propeller of value. Probably with the increased attention that is now being given to the conditions governing the flow of fluids, the better conceptions regarding stream line flow, some of the propeller faddists, together with their fads, will vanish. In the meantime it is necessary to wait for the men with actual knowledge and the ability to dissect their results, it is to this class of men that we must look for progress in the enunciation of the principles of screw propeller design. The commercial value of such data is a factor that cannot be ignored, and the thanks of the members are due to the author for lifting the veil on his section in this interesting field of marine engineering work.

Mr. B. P. Fielden: I was one of those who at the last meeting expressed the opinion that one key was preferable to two in a propeller. I now understand that the author claims that there is less risk in the workmanship being faulty. I differ with him, and think it is doubled.

† In regard to True *v.* Differential Pitch, I have made a diagram showing the angle of entrance of a propeller 18ft. 6in. dia. and 23ft. 6in. pitch, from which it will be seen that at

5 feet	diameter	angle	of entrance	=	$57\frac{1}{2}^\circ$
7 ,,	,,	,,	,,	=	$47\frac{1}{2}^\circ$
9 ,,	,,	,,	,,	=	$41\frac{1}{4}^\circ$
11 ,,	,,	,,	,,	=	35°
13 ,,	,,	,,	,,	=	30°
15 ,,	,,	,,	,,	=	$27\frac{1}{2}^\circ$
17 ,,	,,	,,	,,	=	24°
18 ft. 6 in. ,,	,,	,,		=	$22\frac{1}{2}^\circ$

It appears to me that the inner circle of this propeller is most inefficient, and that differential pitched propellers are designed on better principles than true pitched ones.

Mr. Drewry: At Messrs. Parson's Turbine Works the tests for propellers may be witnessed. The tank has a closed front and back, the electric light is shown through, and you may see the propeller working very clearly, also the air bubbles and the direction of the water of the different propellers, and—what is very interesting to marine engineers—you see the cavitation very clearly. It is an interesting revelation to see the propeller working in the tank. As to the number of keys, one great trouble is due to the makers of shafts not making the keyway true with the shaft. If the keyway is true with the shaft that should be the end of it, but it is not always so; you find your keys bearing hard on the one side aft, and hard on the opposite side forward. The keyway has no

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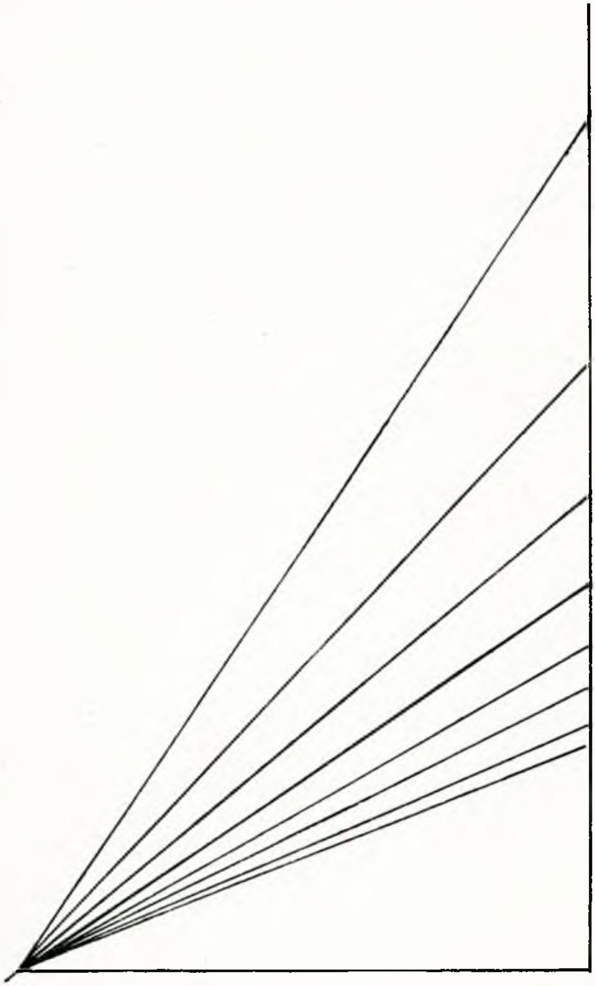
† See page 28

doubt been carefully marked and carefully cut, but it has not been cut carefully enough, and that is, I believe, the greatest cause for bad fitting. From my own experience I find it is



very rare that the keyway is absolutely correct with the line of the shaft. I was surprised to find one of our most successful builders a short time ago use the uniform pitch for the propeller. It may be that they would have been more successful still if they had used the varying pitch, but they used the uniform and got extremely good results; it might have been a happy combination of the ship's runs and other conditions, but I think their results were as good as their rivals.

The CHAIRMAN: I have not had an opportunity of going through this paper, but confirming comments which have been made I may say that I think that of all problems of engineering, the designing of propellers is attended with the greatest amount of trouble. Apart from the formulæ we have for ascertaining strength and pitch, I do not think there is any standard for the form or shape of a propeller blade. It is well known that in the course of two or three voyages, or the life of a ship, the blades frequently go slightly out of shape, the ship has fallen away in her speed, and the blades have been found to be considerably altered. They have been put back into shape, and the ship has then picked up her speed. With regard to the form of propeller blades, this is very variable, for some blades have what is known as the thumb-shaped blade, and other blades have the narrow tip. Some of you may remember seeing a blade that was devised not many years since on the North-East Coast. This practically reduced the bottom portion of the blade to about $\frac{1}{3}$ from the boss and left the effective part just bare for working purposes, the contour of the boss was carried into the rudder and into the hull of the ship, and was claimed to make for great efficiency. The question of a true pitch or a variable pitch is one that was taken up by the late Mr. Thomas Mudd at the Central Marine Engine Works. He had the blade, which was pitched according to his own ideas, of a variable pitch, and he obtained some excellent results. Some prefer a true pitch, others a variable pitch, so that it is rather difficult to set down any hard and fast rules as to propeller blades. The question of balancing propeller blades, was, I believe, carried out to a very fine point when Messrs. Thornycroft were at Chiswick, and they made the blades of steel, three to the boss, ground to a defined weight, fitted, and then balanced as true as possible. This is carried out to-day for battleships. If the blades are accurately machined you have not only a true balance with regard to weight of the blade, but you have an absolutely true surface. Hard and fast lines, I think, can hardly be laid down, because the lines of the ship, and so many other details incidental to every part of the vessel, have to be taken into account, and modern engine builders like to carry out their own designs of propellers, particularly when they are under contract to give a particular speed for which they are paid.

Mr. Wells referred to the swirl of water which we can notice if we carried out an experiment. This is very plainly seen when you take an observation of the boss of a propeller blade, particularly of a twin-screw engine, and notice the driving faces of these blades, you will find markings on the driving side due to coming into contact with the ashes the propeller catches in its swirl, while the opposite propeller you will find free, this is very noticeable after a period of time, and emphasises what has been said with regard to the inward swirl. The question of fitting propeller bosses to shafts, the importance of the manner in which they fit, and the question of one key or two keys, are matters of opinion, more or less, but I am sure Mr. Wells would not care altogether to put a propeller boss on a shaft as described, considering how frequently we have to take them off, and a slack propeller must be avoided by all means, as we depend more particularly on the fitting of the boss to the cone.

Mr. Wells: It is quite unsuitable under these conditions.

The Chairman: I would like to ask Mr. Jackson his estimate of the thrust of this very high speed propeller relative to horsepower, whether 40, 50, or 60 H.P., and how it bears in relationship to larger propellers, and whether there is any penalty against smaller propellers and high revolutions.

Mr. Jas. Shanks: I am pleased to see that Mr. Jackson looks from the practical standpoint—it is the knowledge standpoint. All theories, as far as my experience goes, are only an assistance to aid you after practical experience. Every shipowner and every builder has his own idea about the design of a propeller. Their ideas are simply controlled by their knowledge of what actually gives the best result for certain ships, and the question of a variable pitch versus a uniform pitch, is a very delicate one to discuss at all on theoretical lines, to which Mr. Wells drew our attention. It is most interesting, but I doubt very much if it is of much use to the marine engineer—in fact it is very little utilised. I think, however, that I am fairly safe in saying that the majority of battleships have uniform pitches and give very good results. Sometimes when they are not satisfied with the results they simply change the propeller according to practical information, with very little attention to theory; sometimes they are successful, sometimes not. The screw of a propeller is really one of the most intricate subjects with which the marine engineer has to deal, and it can only be dealt with satisfactorily from a practical point of view.

A Visitor: The question of keys has been sufficiently discussed. It was interesting to hear Mr. Wells' remarks rather supporting the author's contention about two keys, and there was certainly a great deal of sound argument in it. Cases have been tried of closing apertures between propellers as a test for better results, and it was thought such made a decided improvement, but, unfortunately there was not room, in one case referred to, to put more than a single thin plate with no stiffening. The plate was fitted around the aperture, and in course of a short time part of this plate was destroyed, causing a great difference in the areas of the apertures between the blades, yet we could only get the same number of revolutions. A small blade was practically as strong a support as a large blade, but, in a certain case where trials were made between large and small blades, it was the small blades that gave way. It seems the larger the aperture, the disturbances of the water cast a bigger strain on the small blades than on the large ones, because it would appear they were not so proportionately secure, as all the small blades were gone in the trials cited. I met with an unfortunate experience with overlapping propellers in the Suez Canal, where one was bent so badly that the second could not revolve.

The Chairman: A very important point, and one which has received considerable attention recently, is the design of the propeller boss. This is now made as nearly a sphere as possible, and the blades are so fitted as to leave a smooth surface at the root with little or no projections, a long taper cone attached to the boss covering the propeller shaft nut, and at the forward end a rope guard is carefully fitted to follow the contour of the boss. This idea has been further carried out in the solid bronze propeller—which had all parts polished up to reduce frictional resistance to a minimum; this is, however, a somewhat expensive process, and it may be questioned as to its ultimate economy for large steamers. Opinions differ as to the position of the propeller, and as a result of exhaustive tank experiments confirmed by actual experience, it has been found that better results are obtained by fitting the propellers much lower than formerly.

The meeting was then closed with a vote of thanks to the Chairman.

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Reply to Discussion.

Mr. D. H. Jackson writes as follows:—I have read with interest the remarks made at the adjourned discussion on the 16th February. I recognise fully that the shapes of blades shown in my paper by no means represent any approach to finality of design. The subject is certainly a never-ending one: at the same time I think that a plain "set-back" blade (see Fig.6, b) is likely to give as good results as one of the special form described by Mr. Timpson.

I am interested in the method of marking, by smoke, described by Mr. Thom. In this connection, I might say that printer's blue ink, used instead of the usual red lead marking, gives good results, as it forms a very much thinner film, and gives an unmistakable mark. The same gentleman remarks that with different radii at the back and front of the root of the propeller blades, a stronger casting is obtained. In this matter I differ from him. The great point in securing a sound casting, whether of bronze, steel, or iron, is to avoid any sudden change of section. If this is done, with amply large, equal, radii, I fail to see how any advantage can be gained by making the radii unequal.

The question of the efficacy of fixed guide-blades, as an aid to increased propeller efficiency, has long been a moot point. Messrs. Thornycroft undoubtedly obtained very good results by this method; but the practical difficulties attending the fitting of such guide blades are obviously very great. Also the increased friction will go far to neutralise the gain in efficiency. The increased knowledge of the conditions governing steam-line flow has certainly removed some causes of loss.

I think a great objection to the "Differential Pitch" propeller, mentioned by several members, is that a part of each blade, where the pitch is varied from root to tip, is frequently working with "negative slip." This is a most inefficient condition. Also the eddying, due to different velocities at various parts of the stream delivered from the propeller, is a fruitful cause of vibration and corrosion; to say nothing of the internal strains set up in the propeller blades. To my mind, a more promising way of dealing with the innermost portions of propeller blades is to enclose them completely in a false boss of relatively large diameter. This boss, together with the cone at the after-end, and the bossing of the hull for the stern tube, should form a fair line; and should be, if possible, a fair continuation in form of the after-body of the ship. I am convinced that much improvement may be made in this direction, though certainly there are many constructional difficulties to be overcome.

The Chairman spoke of the relative merits of small high-speed propellers, and larger propellers turning at slower revolutions. In practice, it seems that there is no objection to a high speed propeller, provided it is fitted to a high speed ship. For instance, the propeller mentioned in my paper as being remarkably efficient, was run at about 650 revolutions per minute; the speed of the ship being over 35 knots. It would be inadvisable to say the least, to fit such a propeller to a full-bodied ship having a speed of say 10 knots. The ratio of pitch to diameter should not vary greatly, but in practice is usually greater for ships of moderate speed with slow running propellers than for high speed vessels with fast-running propellers; while the thrust per horse-power is of course higher for a slow ship than for a fast one: which means that more propeller surface must be provided, per horse-power, to accommodate that thrust.

Reference to the sketch, Fig. 4, in the paper, will show how largely the area per horse-power has to be increased, as the speed falls away. Of course the curve in that sketch is not claimed to represent the best figures obtainable, or even necessarily figures in accordance with theory; but it is plotted from sundry actual results. Naturally, the types of propelling machinery usually adopted for the different classes of vessel under discussion generally settle the speed, and consequently the size of the propeller in quite a suitable way.

I must not conclude without expressing my thanks to the Chairman and members for their kind interest in my paper; and especially to Mr. Adamson for his kindness in reading it on my behalf.

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