Mr. Thornycroft. could only be known before building a vessel. Great expense was often incurred in making new screw-propellers, because, on trying a vessel, it sometimes happened that the particular period at which the vessel vibrated coincided nearly with that of the period of revolution of the screw-propellers. He might be permitted to mention that costly modifications had been necessary in some of the largest and most expensive vessels running across the Atlantic. With regard to the rapid vibrations which took place in vessels, Mr. Mallock had stated that he had measured 1,500 in a minute. That appeared to be the fourth phase in a particular ship measured, where a vibration so small as $\frac{1}{100}$ inch was equivalent in acceleration to the force of gravity, so that objects would travel on a table and only touch it occasionally. There was one thing that unfortunately happened in ships and required special attention—that, although all the nodes of a ship might be known, and provision be made against vibration, still individual objects, such as binnacles and things standing, as it were, on levers, would synchronise with the engines. He thanked the members for the manner in which the Paper had been received, and acknowledged his indebtedness to the energetic assistance rendered by his staff in its preparation.

Correspondence.

Mr. Durley. Mr. R. J. DURLEY observed that, in the case of the "Daring," the indicated thrust at zero speed amounted to 1,750 lbs., the corresponding quantity for the "Speedy" being 2,800 lbs. These numbers were proportional to the frictional resistance of the main engines in the two cases; and the conclusion was drawn that the smaller loss from friction in the engines of the "Daring" was due to the fact that they were of the four-crank inclined type, as contrasted with the three-crank engines of the "Speedy." The two cases did not seem comparable, inasmuch as the engines of the "Speedy," although of practically the same I.HP. as those of the "Daring," were much larger and heavier, and were driven at a lower speed. It might therefore be expected that the total loss from friction would be less in a smaller and lighter engine, although the mechanical efficiency of the engine would not necessarily be higher. This view seemed to be corroborated by the value of the ratio $\frac{\text{indicated thrust at zero speed}}{\text{indicated thrust at full speed}}$ in the two ships. From approximate figures he found the following values for this relation:— Mr. Durley.

Name.	Indicated Thrust at Zero Speed (T_0).	Indicated Thrust at Full Speed (T_1). $\frac{\text{I.HP.} \times 33{,}000}{S \times 101 \cdot 3}$	$\frac{T_0}{T_1}$
	Lbs.		
Speedy . . .	2,800	74,700 (approx. calc.)	0·0375
Daring . . .	1,750	45,000 (from curve)	0·0389
		53,000 (approx. calc.)	0·0330

The ratio $\frac{T_0}{T_1}$ giving roughly the power of the main engines wasted in friction, the close agreement of these figures would tend to show that there had been no great increase in mechanical efficiency from adopting the four-crank inclined type of engine.

He would be interested to know what, in the opinion of the Authors, was the reason for the great difference between the I.HP. per square foot of heating-surface of the boilers of the two ships in question, as shown in the following Table:—

Name.	I.HP. per Square Foot of Grate.	I.HP. per Ton of Boilers.	I.HP. per Square Foot of Heating-Surface.
Speedy	23·0	43·9	0·27
Daring	23·3	91·0	0·55

With nearly the same I.HP. per square foot of grate, the heating-surface in the case of the "Daring" was much more efficient.

Mr. B. F. Isherwood, Chief Engineer of the United States Navy, had always been of the opinion that torpedo-boats and torpedo-boat destroyers were too small for effective use except in smooth water and under particular circumstances unlikely to occur in the naval practice of great nations. Such vessels could be useful only in restricted littoral warfare. In the open sea they would prove useless and generally disastrous. They could not affect the result of any naval war, and it was probable that the money expended on them would produce better results if applied to the construction of sufficiently large sea-going vessels. The tendency from the beginning had been towards the enlargement of these vessels. That was inevitable, and would continue until they were merged into first-class gunboats or small corvettes capable of service at sea, Mr. Isherwood.

Mr. Isherwood. when they would cease to be torpedo-boats, although the name might survive.

Independently, however, of the value of such vessels as war-ships, lessons were to be learned from them in the dynamics of naval architecture which could not be derived from any other kind of vessel; because none were constructed of so small a weight per square foot of the vessel's horizontal projection, with so small a draught proportional to length, or with such high speed. The combination of these three factors enabled the torpedo-boat, at very high speeds, to rise in the water, so that the mean draught at the highest speed would be less than at lower speeds, less immersed midship section and less surface resistance to the water being thus exposed. The immersed form of the vessel should be modelled to attain this result, the bottom of the fore body being made an inclined plane up which the vessel was driven or lifted when its forward resistance was greater than its weight. The resistance increased in a much higher ratio than the square of the speed, but the weight remaining constant. These facts indicated that, in the case of vessels of small weight per square foot of horizontal projection, of great length relative to the draught, and attaining a very high speed, additional speed could be obtained without increase of power proportional to the ratio of power to speed at lower velocities. He inquired whether these factors, in the vessels described by the Authors, were of such values as to produce the lifting action. The answer could only be given as the result of experiment, but trials could easily be made with certainty. He suggested the following method: at each end of the vessel to be experimented upon, let there be provided a graduated plumbed rod and movable target, such as employed in levelling operations. On the shore, convenient to any course over which the vessel could be properly run—a course with sufficient depth and breadth of water to secure normal results—let there be mounted a levelling instrument, and let the vessel be placed before it, and let the targets on the rods be moved up or down until their centres coincided with the cross-hairs in the telescope of the instrument, the reading on the rod being noted. Then let the vessel be driven at various speeds up to the maximum, forward and backward before the instrument, and for each speed let the targets be moved as before until their centres again corresponded with the cross-hairs of the instrument, the reading on the rods at the centres of the targets being again noted. A comparison of the figures obtained from the rods when the vessel was in motion with those obtained when the vessel was at rest, would give

Mr. Isherwood.

accurately the variations of the trim for each speed, and would also show how much the vessel had risen in the water at each speed, if at all. The speed of the vessel would be given by that of its screw at the moment the observations on the rods were taken, the number of revolutions being obtained from a mechanical counter for any convenient interval of time, say, five minutes to ten minutes. The length of the course for small vessels need not exceed a few hundred yards, and the means of the observations for both directions should be taken in order to neutralise the effect of the wind. There must be no appreciable rise or fall of the tide during an experiment. The speed of the vessel corresponding to the number of revolutions made by the screw per minute would be obtained from curves derived from a series of progressive trials. Such experiments should be made on all vessels where practicable, for the improvement of naval architecture and for the determination of the laws of the resistance of water to moving ship-formed solids partially immersed. In the case of small vessels like torpedo-boats, with which exhaustive and exact experiments could be conveniently made without great expense, it was well worth the while of builders, who constructed them by contract with guaranteed results, to make such experiments as would enable them to work with the greatest certainty and the least cost; for, although the desired results might finally be arrived at tentatively by trial and error on the large scale, such a process was always expensive and frequently unsuccessful. Reliance was to be placed only on instrumental measurements, opinions based on general observations unaided by such measurements being valueless. The importance of such considerations might be measured by the fact stated by the Authors that the guaranteed speed of some torpedo-boat catchers had been, on their trials, exceeded by between 1 knot and 2 knots, which showed that their designers were not sure, as regarded dimensions and power, of what would produce the required results, and therefore had to secure them by the use of an excess of material and labour. The cost of producing the additional and uncompensated speed would probably have paid for many experiments to enable a closer approximation to be made.

It was stated in the Paper that all the screws employed had expanding pitches from fore to aft, and that their slips had been calculated from their mean pitch. This method was erroneous; the slip of a screw with fore-and-aft expanding pitch should be calculated from the aft or final pitch. The true slip of a screw was the speed with which the water left it relatively to that of the

Mr. Isherwood. vessel, the former being determined by the final pitch alone. The thrust of a screw was always much less than that calculated from the mean pressure on the indicator-diagram by reducing the pressure on the crankpin in the ratio of the length of a double stroke of the piston to the length of the pitch. The true thrust had no fixed relation to the imaginary "indicator thrust," and the latter had no value for any purpose; whatever deductions might be drawn from it were necessarily erroneous. It was also stated (p. 59) that the heeling outwards of a vessel turning in a circle was due to centrifugal force. When a vessel turned, its centre of gravity only described the circle; its keel lay across the circumference, with the stem inside and the sternpost outside it. The movement in the circle was caused solely by the simultaneous forward movement of the vessel in the line of its keel given by its propeller, and its rotation on its centre of gravity given by the rudder. The heeling of a vessel turning in a circle was due entirely to the vertical distance between the horizontal planes in which lay the centre of pressure of the rudder and the centre of lateral resistance of the vessel. The direction of heel was outwards or inwards accordingly as the former was above or below the latter plane; and its amount, other things being equal, was proportional to the distance between the two planes. If the planes coincided, there would be no heel, however great the speed of the vessel. The heeling action was in no way due to centrifugal force. When the centre of gravity of a vessel described a circle, the continuous deflection of the keel from the tangents of the circle was not caused by the action of a central force, as in the case of the gravitation of the planets, or in that of a stone whirled in a sling, but was caused solely by the action of the rudder.

Mr. Normand. Mr. J. A. NORMAND remarked that the experiments on the French torpedo-boat 153, to which the Authors alluded at the end of the Paper, had shown that the diameter, blade-area and immersion of screw were more than sufficient to avoid the rupture of the propulsive column of water when under weigh in smooth water. He believed that higher speeds could have been attained with screws of less resistance, and with the axis of the shaft more nearly parallel to the flow of water at the stern. But the screw had been so proportioned and immersed as to prevent rupture in a heavy sea, with the increase of displacement which could not be avoided in service, whatever might be the weights on board during the trials; and to this was due the remarkably small loss of speed experienced in service by boats of this type. The same had previously been observed in the comparative trials in Spain and

Russia, the Normand boats then tried having very large screws. The advantage thus gained was probably more important than that to be derived from a very small draught of water. According to the Authors "the speed of vessels has now approached within measurable distance of that at which propulsion by screws depending upon the reaction of water, becomes inefficient." He could not see reason for a limitation to the speed, provided the resistance of the screws augmented in the same rate as the resistance of the hull with the increase of speed. Mr. Normand.

THE AUTHORS, in reply to the Correspondence, observed that Mr. Durley had advanced the view that in two engines of the same indicated horse-power, the loss from friction (by which term his calculations showed he meant that portion of the indicated thrust which was neutralized by friction) might be expected to be less in the smaller engine, although its mechanical efficiency would not necessarily be higher. Was not this equivalent to saying that if from two equal quantities unequal amounts were deducted, the remainder would not necessarily be greater in the case where the least quantity had been subtracted? In calculating indicated thrust, the Authors had followed the method employed by the late Mr. Froude, who took it as $\frac{\text{I.HP.} \times 33{,}000}{\text{pitch} \times \text{number of revolutions}}$. Since Mr. Durley's third column was calculated in a different way it could not be compared with the second column. When calculated in the manner employed in the Paper, the thrust at full speed was 57,300 lbs. for the "Speedy" and 44,400 lbs. for the "Daring," giving efficiencies of $\frac{44{,}400 - 1{,}750}{44{,}400} \times 100 = 96 \cdot 9$ and $\frac{57{,}300 - 2{,}800}{57{,}300} \times 100 = 91 \cdot 6$ for those vessels respectively. The "Daring" was thus $5 \cdot 3$ per cent. more efficient than the "Speedy." It was a matter of common experience that, in two engines of similar design, the larger one was the more efficient; so that to have obtained a higher efficiency with the smaller engine, pointed, in the Authors' opinion, to a considerable improvement in the "Daring" design as compared with that of the "Speedy." In reply to Mr. Durley's question as to the reason why the indicated horse-power obtained per square foot of heating-surface was so much greater in the "Daring" than in the "Speedy," the former was forced much harder, that is, more coal was burned per foot of heating-surface. As the grate-area was much larger in relation to the heating-surface in the boilers of the "Daring" than in those of the "Speedy," the coal burned per square foot of grate-area did not differ greatly in the two cases. The Authors.

The Authors. In reply to Mr. Isherwood, the Authors did not desire to discuss the value of torpedo-boats either for littoral warfare or for use in the open sea. The question as to whether or not money expended on them would produce better results if applied to the construction of large sea-going vessels, lay outside the scope of the Paper. A large number of torpedo-boats were in existence, and an efficient vessel was required for their destruction. The first-class gun-boats and small corvettes preferred by Mr. Isherwood existed also in numbers in the British Navy and did good service. The "destroyer" did not supplant them but supplemented them, and its superior speed enabled it to overhaul the torpedo-boat in any weather.

Although it might be possible to get small, heavily-powered, specially-constructed vessels to lift themselves in the water in the manner described by Mr. Isherwood, the Authors did not think any action of the sort took place in the destroyers, and doubted whether such an experiment as that suggested by him—even if the difficulties of making it could be overcome—would establish the fact of their lifting in the water. It would merely show a rise or fall as compared with still water; but the whole surface of the water in the neighbourhood of the vessel was affected by its passage at high speed; and the vessel might be borne up on the crest of a wave travelling with it, or even be depressed by lying in a trough, without the occurrence of any change in mean draught.

The Authors were aware that the true slip of an expanding-pitch propeller was not correctly obtained from the mean of the pitches of the forward and after edges, and they had been careful to point out that the effective pitch was greater than the mean thus obtained. In the screws of the "Daring," the pitch did not increase uniformly from forward to aft, nor was it the same for the whole of the after edge; and it was by no means a simple matter to determine the real pitch and slip of a screw so constructed. They had considered that for their purpose the method employed was the best. The objections of Mr. Isherwood to the use of "indicated thrust" were not shared by the Authors. It had been employed by the late Mr. Froude as a means of comparing the initial friction of engines, and for this purpose it appeared to the Authors to be useful. Of course, it was always greater than the true thrust. It might be said to represent the true thrust produced by a frictionless engine and propeller, the propeller moreover being so placed as to produce no augmentation of resistance.

They could not agree with Mr. Isherwood's explanation of the

The Authors.

behaviour of a vessel when turning a circle. The Authors, on the contrary, believed that a vessel heeled outwards in turning owing to centrifugal force. When a ship had acquired momentum in a straight line, and was more or less suddenly constrained to move in a circle, the momentum acting through the centre of gravity of the whole body tended to cause the centre of gravity to continue to move in a straight line tangential to the circle in which the ship was constrained to move. It was prevented from doing so by the side-wise resistance of the ship, which had been forced by the rudder to assume a position oblique to her former direction. This side-wise resistance acted nearly through the centre of area of the immersed vertical longitudinal section, which was always below the centre of gravity, and a heeling-couple was thus produced. The higher the ship's centre of gravity, the more would she tend to heel out, due to the centrifugal tendency of the centre of gravity. If the rudders were placed low, the pressure upon them tended to counteract the outward heel, and would sometimes, as in the "Daring," force the vessel to heel inwards.

The Authors quite agreed with Mr. Normand that it was wise when possible to make the screws somewhat larger than was necessary for smooth-water trials at designed draughts in order to avoid excessive slip in rough weather and when deeply loaded [1]; but it sometimes happened that the conditions of trial were so onerous that no sacrifice of efficiency under these conditions could be accepted. They also agreed with him that no limitation to the efficient performance of the screw need be anticipated, provided the resistance of the screw augmented at the same rate as the resistance of the hull with increase of speed; but they found in the "Daring" that the resistance of the screw, or in other words, the thrust with a given slip-ratio, did not so augment.

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9 April, 1895.

SIR BENJAMIN BAKER, K.C.M.G., Vice-President, in the Chair.

The discussion upon the Paper on "Torpedo-Boat Destroyers" occupied the evening.

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[1] Minutes of Proceedings Inst. C.E., vol. cii., p. 81.