3rd. How does the Indicated Power curve come out? In what ratio does the power required increase? At what point does the power curve cross the cube line? And what is the maximum and most economical speed at which this and similar hulls can be driven?

4th. How does the efficiency of your double-ended screws compare with single screws when calculated by Froude's curve of indicated thrust?

5th. Do you use Kirk's Analysis when getting out the wetted surface? How much I.H.P. is required to drive 100 feet of wetted surface through the water at different speeds?

6th. With equal powers, how much more resistance is experienced in driving the immersed midship section at different speeds, than in a similar section propelled by a single screw? &c.

All the above and other questions would doubtless be asked. What could we say in reply? Not much, certainly. We would have to frankly admit our inability to answer any of them, the probable excuse being that we had certain methods which, although somewhat primitive, were quite sufficient for our purpose, and that we could build vessels and fit them with the required power without any scientific assistance. He could imagine the quiet smile with which such an excuse would be received; and what would they say when they got home, possibly something like the following.—

"What a wonderful place Sydney is for harbour steamers; they have over 250 of them, and for this particular traffic double-ended screws are found to be most suitable. Generally, these craft are really well built, having good lines, with plenty of power, besides being well finished and comfortably fitted. We had ample evidence of an exceptional amount of energy and enterprise, but what surprised us most was, that although they have built so many steamers, not only for harbour, but also for sea service, they have no information or data by which the efficiency of one ship could be compared with another, and evidently do not realise the importance and necessity of *Progressive Trials*, which is the only way of obtaining a really large amount of useful information that would materially assist both shipbuilder and engineer in the design and construction of new vessels, &c., &c."

To show what "Progressive Trials" consist of, and how they are carried out was his (the speaker's) principal object in speaking. The drawings (Plates XVI., XVII.) before you represented the "Progressive Trials" of the new pilot steamer "Captain Cook," and, so far as he was aware, were the only complete trials ever carried out on this side of the line. The credit of suggesting them was not due to himself, but to Mr. Christie, who had also done the lion's share in working out the various calculations. Through the courtesy of Mr. Franki, Mr. Christie had enlarged the original drawings so that they could be more distinctly seen, and probably better understood. The foundation of the system, as shown in drawings, depended on the fact that it was just as important to know the power required to drive vessels at low and variable speeds as at full speed. To determine this it became necessary to run over the measured knot a number of times, with and against tide, and it was always desirable to start the first run at the lowest possible speed, gradually increasing until the maximum was reached. In the "Captain Cook's" trials we had everything in our favour—a beautiful day, smooth water, very little tide, and not a single stoppage. Her first run was with 60 revolutions, which gave a speed of 6·6 knots, a double set of diagrams being taken both up and down, which, when worked out, told us it required 100 indicated horse-power to drive her at that speed, the slip of the screw being 9 per cent. This gave us the first point in the indicated power curve. The second run with 83 revolutions gave a speed of 9 knots, the cards showing that it required 240 I.H.P. to do it, the slip being 10 per cent. This gave the second point in curve. Third run with 101 revolutions gave a speed of 11 knots, the indicated power being 420, with $11\frac{1}{2}$ per cent. slip. This constituted the third point in curve. Fourth run—engines going 116 revolutions gave a speed of 12 knots, with 590 I.H.P., the slip being $14\frac{1}{2}$ per cent. This represented the fourth point in curve. Fifth run going 125 revolutions gave a speed of 12·6 knots, I.H.P. being 765, slip 16 per cent., which gave the fifth point in curve. The sixth and last run, full speed, gave the maximum speed and power, 12·87 knots and 833 I.H.P., slip 18 per cent., forming the last and final point in curve.

To ensure accuracy each run was made both ways, with and against tide, and the true mean time taken. Double sets of diagrams were also taken, both up and down, and their true mean determined. The time, steam, revolutions, vacuum, &c., were duly checked by different observers, and generally every care was exercised to get correct data.

Having obtained these six points the base line on drawings was drawn and divided into a scale of knots, the perpendicular ordinates, also to scale, representing the I.H.P., and which showed at a glance the power required to drive the vessel at any of the points taken, or at any intermediate speed up to the maximum.

When indicating 100 horse-power we got 6·6 knots, but to drive her 12·8 knots required 833 horse-power, $8\frac{1}{3}$ times as much. Then this power curve showed very clearly that the most economical speed would be 11 knots, because we could get that with 420 I.H.P., whereas to increase it from 11 to 12·8 we had to double the power, which demonstrated the enormous increase in the ship's resistance after passing 11 knots.

The shape of the curve near and at full power told us in a very decided manner that we had attained the maximum speed at which this hull could be driven, also that any attempt to increase it would be a great and useless waste of power.

To show how this information might be utilized, assume one of the other Colonies decided to build a similar vessel for the same purpose; that they approved of hull, lines, &c., but they stipulated for a 14 knot speed, and they increased the power accordingly; if we had no information to check this proposal, then a grave mistake would be made, which could only be found out when too late; but with the result of the progressive trials in our possession we could with all confidence point out that it would be no use putting more power in that hull, because if she was filled with machinery she would not—in fact, could not—go that speed; and if 14 knots was to be the speed, it must be with a different hull and different lines, &c.

Again, take the "Lady Manning," for instance, and assume the Company decided to build another vessel off the same lines, and that they put in, say, thirty per cent. more power, with a view of increasing the speed, it was very doubtful if it could be got; in fact, it was more than probable this extra power would be wasted.

What we wanted was the same information and data for our double-ended screws and our steam fleet generally as we had in connection with our pilot steamer, which would enable us to at all events approximately determine, not only what should be done, but whether it was possible to do it at all, and also what alterations must be made in order to materially increase the efficiency and economy of our vessels.

For many years before the days of "progressive trials" it was generally received as an axiom that the power required to drive a ship through the water increased as the cube of the speed, and that the frictional resistance varied as the square of the speed. This, however, although it might apply in some cases, was not correct; and we were specially indebted to Denny, of Dumbarton, for much valuable information on this subject. He was one of the first men who thoroughly appreciated the importance and value of progressive trials, and his labours in this direction were invariably regarded as authorative and standard data. He carried out his experiments sparing no expense in his own works, and had a special tank constructed, over 400 feet long, where carefully made and proportioned models of every ship built were accurately tried, and all the necessary information collected and graphically developed in a somewhat similar, but possibly more elaborate, manner than in the drawings before you.

What Denny proved was this: that the power required did not necessarily increase as the cube, nor the ship's resistance as the square of the speed; but that power and resistance were variable qualities, which might and did vary considerably in different ships and at different speeds; also that each ship had a co-efficient of power ratio of its own, and that, from a practical point of view, progressive trials, carried out as previously described, were a good and reliable method of obtaining the necessary information, in order to insure satisfactory results; and it was no exaggeration to say that the data at the command of this celebrated firm was considered to be one of its most valuable assets, which had been so successfully utilised that every steamer built by Denny proved capable, and in many cases more than capable, of fulfilling the conditions of contract.

Another eminent worker in this branch of science was the late Mr. Froude, a man of exceptional talent, and whose power of explanation was on a par with such men as Faraday, Tyndall, and Ball; for, like them, he was richly endowed with that rare gift of making complex subjects plain and easily understood. He was commissioned by the British Government to carry out extensive experiments on the power and speed of ships in his own way, and without the slightest restriction. This he did most effectually, his labours taking the form of a series of papers read before the "Institution of Naval Architects," and which were unanimously allowed to be the most important ever published.

Rankin was also a valuable contributor, and his system when thoroughly carried out was perhaps the most accurate, but it was much more complex, entailed a lot of work, and as there was always considerable difficulty in collecting the necessary data, more practical methods were generally used.

Referring to the drawings, the whole of the "Captain Cook's" performance was graphically developed on one sheet of paper, and an experienced eye could tell at a glance if the results obtained were good, bad, or indifferent; could point out any radical faults, possibly rectify them, and would probably be able to determine what alterations were necessary when building similar ships to ensure increased speed and efficiency without any excessive waste of power.

It would be observed that in this case all the standard formulæ for determining power and speed were graphically represented by eight curves, viz.:—

Two Slip Curves
Displacement Curve
Indicated Power Curve
Indicated Thrust Curve
Curve of Revolutions
Curve of Immersed Midship Section
Curve of Wetted Surface.

To explain in detail the derivation and application of these curves was a large contract, and quite beyond the scope of the present effort, and, as before stated, could only be referred to briefly and in general terms.

The two slip curves simply represented the difference between the speed of the screw and the speed of the ship; one showing the slip in knots, the other the slip per cent., read off the same scale as the I.H.P., with this difference, that, for percentage, every 10 h.p. was equivalent to 1 per cent., and for slip in knots every 100 h.p. represents one knot.

The displacement curve was based on the assumption of the power required, increasing as the cube and the resistance as the square of the speed. They, however, had been proved to be variable, and not constant qualities; but when put in the form shown on drawings, viz., the cube root of the displacement squared, multiplied by the cube of the speed, and divided by a constant deduced from actual progressive trials, the quotient would give the I.H.P. necessary to drive the ship at the required speed, provided always the selection of such constant was in experienced hands. This was usually expressed as—

$$\text{I.H.P.} = \frac{D^{\frac{2}{3}} \times S^3}{C}$$

Where D = Displacement in tons
,, S = Speed in knots
,, C = Constant from actual experiment.

Then with respect to curve of immersed midship section, it was generally accepted that the resistance would bear a direct relation to the immersed transverse sectional area to be driven through the water, and which must of necessity be the measure of the channel swept out by the ship. That being so, if the area of immersed midship section be multiplied by the cube of the speed and divided by a constant, also deduced from practice, the I.H.P. for the required speed was obtained and expressed thus:—

$$\text{I.H.P.} = \frac{\text{Area of immersed midship section} \times S^3}{C}$$

These two rules for many years represented the usual practice for determining the power required for a given speed. Their approximate accuracy depended on this, that the wetted skin varied nearly with the displacement in vessels of similar form, and that the cardinal proportions were such that the wetted skin varied nearly with the area of immersed section; but, as previously stated, it required both experience and judgment in determining upon the constants.

The I.H.P. curve had already been dealt with, and required no further explanation.

The curve of revolutions practically explained itself, and would be useful and reliable in dark or thick weather, as the time required to cover any known distance could always be determined with approximate accuracy. Every shipmaster should have one.

For the curve of indicated thrust we were indebted to Froude, and it was an extension and improvement of Denny's power curve. This curve was constructed in precisely the same manner as for the I.H.P., with this difference, that the perpendicular ordinates represent the indicated thrust at the different speeds, which gave the necessary points through which the curve could be drawn, the base requiring no alteration.

Curves of indicated thrust were considered more valuable than the I.H.P. curve, and were used in the Navy in preference to others. By this curve we could, by a simple geometrical construction, get at the thrust due to the initial or constant friction of the machinery, whereas the indicated horse-power included ship, engines and screw, which was not so reliable as when separated and reduced to a force factor, which Froude did by dividing the indicated horse-power expressed in foot pounds by the speed of screw in feet per minute, the result being termed the indicated thrust, at the various speeds, expressed thus:—

$$\frac{\text{I.H.P.} \times 33{,}000}{\text{Pitch} \times \text{Revolutions}} = \text{Thrust.}$$

This thrust was read off the same scale as the I.H.P., and was expressed in tons, every ten divisions being equal to one ton. One of Froude's most important discoveries, intimately connected with this thrust curve, was that where he determined how the power passed through the engines was actually expended, and how much of it was lost, and why. He found that in a screw steamer of ordinary form a loss of 40 per cent. of the S.H.P. was due to the effect of the screw on the water under stern of ship. If there was no screw the water displaced at the bow would naturally tend to close in at the stern and cause a forward pressure there. The action of the screw withdrawing this water lessened the pressure under stern, which was equivalent to increasing the ship's resistance, hence this great loss. Another cause of loss was the oblique action of the blades on the water, which was equal to about 10 per cent. Then inside we had losses due to dead weight of working parts, friction of engines, power required to drive pumps, &c., which, when added together, brought the loss of power up to 60 per cent., so that in ships of ordinary form only about 40 per cent. of the indicated power was utilized in actually driving the ship.

The curve of "wetted surface" was also used in determining the power required. It had been generally considered that the amount of wetted surface to be driven had a direct relationship to the power necessary to drive it, and from a number of progressive trials certain co-efficients had been deduced which told what I.H.P. was required to drive 100 feet of wetted surface through the water at certain speeds, ten knots forming the basis. To find the amount of wetted surface in the first instance was usually calculated by Kirk's "Analysis" or block model system, a description of which would be found in Seaton's and other text books. By this method we could get within 5 per cent. of the actual surface, and this was near enough in practice.

This was a brief and very imperfect description of a subject having such a vast range that he had only touched its outer fringe, but had perhaps said enough to show the value and necessity of progressive trials, also that we were far behind in this connection, and that although such trials meant a considerable amount of work, yet the information gained was worth all the trouble twenty times over.

In conclusion, it is desirable to point out that although the various rules and formula shown on drawings were not perfect, still they were fairly good approximations, which, in experienced hands had, to a large extent, been the means of enabling the British naval architect and engineer to build up and retain a reputation, that every ship's performance would be in harmony, and probably in excess of what was guaranteed.