Mr. Armstrong suggested, that the discussion should first be taken upon the question, whether the propelling power varied as the square, or as the cube of the velocity. The latter theory was the one generally received as correct, and if it was proved to obtain, all the deductions he had drawn from the opposite theory would of course be erroneous. What he intended to convey was, that in all cases the resistance was as the square of the velocity, and that the propelling power was in the same proportion as the resistance. The speeds were given throughout in statute miles.

Mr. J. Scott Russell said, the Admiralty experiments were recorded in knots. He had some difficulty in arriving at the exact ideas of the Author on several points. In some instances the phrase employed was "that the resistance was as the square of the velocity;" in others, "that the indicated horse-power was as the square of the velocity." There seemed to be some confusion in the Paper, in the use of the terms "power," "force," and "resistance." Power was the force developed in a given time, and consisted of two elements,—force, and the space moved over. All naval constructors agreed, that the resistance and the moving forces varied as the square of the velocity; and in calculating the resistance, or force necessary to propel the vessel, they had always taken the area of the largest, or main section, as the principal element. Now, if the resistance was as the square of the velocity, then the horse-power expended, multiplied into any number of square feet of main section, must, as a mere mathematical rule, be as the cube. For instance, if the resistance to 1 square foot of midship section, propelled at the rate of 5 miles an hour, was 5 lbs., then, according to the usual known law of the resistance being as the square of the velocity, the resistance at 10 miles an hour would be four times five, or 20 lbs. But this latter resistance acted over double the space, so that the result must be again doubled, for the measure of the power expended; and hence, the power developed in one hour, was necessarily and unavoidably as the cube of the velocity. The Author's proposition about the measure of power was, therefore, in direct contradiction to his admission as to resistance. Mr. Russell held, that no further discussion was necessary upon that subject; but all that had been advanced about resistance, in so far as correct, must be allowed, as being merely what everybody already knew. The Author was, however, entitled to demand, that his theory should be tested, not merely by the ordinary rules of arithmetic, but also by facts and figures. The figures which had been brought forward in the Paper, must be assumed to be, and be taken as, facts soundly calculated; but unfortunately for the Author, they overthrew his arguments. One table contained collected facts, and another selected facts; the latter approaching the nearest to the demonstration of the "square" theory. In this selection, the "square" theory was nearer to the fact than the "cube" theory, or ordinary rule, in the cases of the 'Minx,' 'Himalaya,' and 'Vulcan;' whilst the ordinary rule was much more nearly correct in the 'Archer,' 'Dauntless,' 'Fairy,' and 'Plumper.' The selected facts, therefore, failed to prove the rule they were intended to support. In the table of collected facts, the actual speeds were

8·4, 9·4, 8·9, 9·4, ... 8·7, 10, 12, 7·2

The speeds calculated by the "square" theory were

7·0, 7·7, 7·8, 8·4, ... 10·15, 13, 14·7, 11·83

Thus, it would be seen, that there were two diverging series of figures, which, arranged in columns, side by side, must agree somewhere about the middle. At the commencement of the table, the formula gave the speed as less than it really was; in the middle, fact and calculation nearly agreed; whilst at the end of the table, the rule gave results greatly in excess of the truth. If that was to prove the formula, he confessed he had yet something to learn in the mode of proving a formula. The time had not yet arrived when a simple formula would make a ship go fast, nor when the shape and lines of a ship could be disregarded, nor could it be admitted that, by merely allotting so many horses' power per foot of midship section, so much more speed could be obtained.

He recollected witnessing an experiment, the first of the kind he had seen, at the measured mile on the River Thames, whilst the late Mr. Ewart was Inspector of Machinery for the Admiralty. Two engines of 50 H.P. were taken out of a man-of-war, and were replaced by a pair of engines of 60 H.P. The practical result of the alteration was, that only one-twentieth part of a mile more speed was obtained by the engines of 60 H.P., than by those of 50 H.P. That was one of the first facts to satisfy his mind, that horse-power was not everything, but that the shape of the ship was something; and he determined, if possible, in future not to trust to mere horse-power, but to see what could be done by the shape of the ship. Soon after that, he had an opportunity of superintending the building of four timber ships of the same dimensions, the same displacement, and the same horse-power; but each had different lines, being constructed by four different builders. The engines were all alike, being made by the firm to which he belonged, and the same firm also built one of the vessels. The result was, that upon a run of 16 miles, their several speeds were $12\frac{1}{2}$—12—under 11—and something between 10 and 11 miles per hour. He would mention another instance; a steam-vessel, constructed to go both ways, but built with one fine end, and the other less fine, as an experiment, went fully a knot faster one way than the other, although the midship section and the horse-power were necessarily identical at all times. This showed, that there was something more than engineering in the construction of a steam-vessel. He afterwards built four other vessels, of identical length and breadth, the other conditions being similar; the result was, that in one ship the resistance was double what it was in another. That being the case, he thought there was no reason to doubt the correctness of the general rule, that the resistance of similar forms was as the square of the velocity, and the horse-power as the cube of the velocity, which came very near to the results of practice; where the forms varied no such conclusion could be warranted. If it was said, that Naval Architecture had not made as much progress in the present century as might have been expected, it was not, at least, owing to a want of formulæ.

Mr. Russell thought it very desirable, that they should have good facts and experiments, and not new formulæ, and that results should be attributed to their proper causes. Experiments were still wanting, to determine how much force it took to drag a vessel of a given shape and a given size through the water, at a given speed. The experiments should be made by towing vessels, so as to get true measures of resistance, without being mixed up with the engine and the slip of the paddle-wheel. He suggested, that the Government should institute a series of experiments for this purpose, and that the 'Duke of Wellington' should be towed by several steamers with a rope, at speeds of $2\frac{1}{2}$, 5, $7\frac{1}{2}$, and 10 knots per hour, and the drag upon the rope be ascertained by means of a dynamometer. A similar series of experiments with such a vessel as Her Majesty's yacht, which had fine lines and great length, would give results from two totally different classes of ships; and such experiments would do much more to advance the science of Naval Architecture, than the mere construction of empirical formulæ.

Mr. DINNEN remarked, through the SECRETARY, that a series of trials made by him in 1852, in the channel, and under the same circumstances, on board H.M.S. 'Desperate,' of 1,037 tons burthen, and 400 nominal horse-power, confirmed, in a remarkable degree, the usually received theory, that the velocity of the ship varied as the cube root of the power, and not as the square root. The trials were usually of eight hours' duration; but were occasionally brought to a close in six hours, or less, if circumstances threatened to affect valuable results already obtained. The steam was kept at a constant pressure in the boilers, and indicator diagrams were taken from each of four cylinders every quarter of an hour; the mean of the whole being taken for the exponent of the trial. The revolutions of the engines were taken by two counters, and the speed of the ship by three patent logs—the mean, of course, being taken for the results. The engines were adapted for being readily separated into pairs. The results of these trials, expressed in a tabular form, were thus recorded :—

Experiment.	No. of Trials.	Depth of Water.	Indicated H.P.	Speed in Knots.	Mean Expenditure of Coal per Indicated H.P.
		ft. in.			lbs.
No. 1, with 4 boilers and 4 cylinders	3	15 6½	805·894	9·147	4·61
No. 2, with 3 boilers and 4 cylinders expansively . .	2	15 8¾	579·319	8·248	5·13
No. 3, with 2 boilers and 4 cylinders expansively . .	2	15 6¾	363·867	7·352	5·58
No. 4, with 1 boiler and 2 cylinders expansively . .	1	15 1	169·32	5·981	5·89

Now, if, as had been for a long time received, the velocity of the ship varied as the cube root of the power, and not as the square root, it would be expected, that the index of the full power, as well as of the others, would correspond. This they did in a most remarkable degree. The slight difference in the draft of water of the ship could not materially affect the results, inasmuch as he had known three times the difference to be immaterial to speed and power, when the lines did not alter rapidly. Many other illustrations might be adduced, as to the law of the relation of power to velocity, confirming the results of the trials with the 'Desperate.'

In these trials, the expenditure of hand-picked Welsh coal, per indicated H.P. per hour, was never lower than 4·4 lbs., nor higher than 5·9 lbs. in any of the experiments, the least economic result being obtained when only one boiler, out of four, was employed. The consumption of 4·4 lbs. might be taken as the most economic expenditure per indicated H.P. per hour of the engines in question, at their fullest work, with clean Welsh coal, urged to a rate of combustion of about 18 lbs. per square foot of grate per hour, with four boilers.

Mr. C. Atherton observed, through the Secretary, that he believed the Author of the Paper under discussion attempted to establish the following propositions :—

1st. That the comparative speed of two vessels, with an equal moving power in each, did not depend on any form, but entirely on the area of the immersed midship section, or the greatest section at right angles to the line of motion.

2nd. That with a given sectional area, additional displacement in the line of motion did not materially add to the resistance.

3rd. That to propel a vessel twice as fast only four times the power was required.

4th. That the amount of friction between the hull and the water did not affect the calculation for any required velocity.

In these propositions Mr. Atherton could not concur, for the reasons which he would briefly state.

With regard to the first proposition, H.M.S. 'Rifleman,' originally with 348 indicated H.P., only attained a speed of 8·09 knots per hour, but when her stern lines were altered a speed of $9\frac{1}{2}$ knots was attained, with 367 indicated H.P., and when the power was reduced to 188 indicated H.P., the speed was 8·01 knots; being nearly identical with the speed which originally required 348 indicated H.P. Again, H.M.S. 'Teazer' originally required 176 indicated H.P. to attain the speed of 6·31 knots; but with reduced engines, working to 128 indicated H.P., after the stern lines had been made finer, the increased speed of 7·68 knots was attained. H.M.S. 'Bann' and 'Brune,' fitted with a rudder at each end, and, therefore, capable of being worked at full power in either direction, were found to have a greater speed when going ahead, than when going astern, the indicated horse-power being the same in both cases. Experimental trials with H.M.S. 'Dwarf' showed, that the speed could be reduced to less than one half, by filling up, or doubling upon her stern lines; and the original speed could be again restored by removing the doubling—the indicated horse-power being in both cases the same. In all these experiments, the midship section of the respective vessels was in no way interfered with, and the hulls were clean at the time of trial.

With reference to the second proposition, estimating the comparative dynamic duty of vessels by the generally received law—$\frac{V^3 D^{\frac{2}{3}}}{\text{Ind. H.P.}}$, his experience led him to believe, that there was a limit to the advantageous increase of the length in proportion to the beam. The decrease of resistance, resulting from the finer lines, obtained by an extension of length, was, after certain limits, more than neutralized, by the increase of frictional resistance, occasioned by the corresponding increase of surface.

With regard to the third proposition, on the relations of power and speed, H.M.S. 'Minx,' when propelled by 31·6 indicated H.P., attained the speed of 4·51 knots per hour, but to propel the vessel at 9·14 knots required 234 indicated H.P., or nearly as the cube of the speed. By the "square" theory, the speed (9·14 knots) ought to have been attained by 130 indicated H.P. The same rule, that the power varied, *cæteris paribus*, as the cube of the speed very nearly, had been found to obtain with H.M.S. 'Banshee,' which had been adapted for different services, requiring a variation of speed from 12 knots to 16 knots.

In reference to the fourth proposition, it was quite common, in Her Majesty's service, for vessels to be tried at the measured knot, before leaving the Thames for foreign service, and again after their return. It was thus frequently found, that the speed was reduced as much as 20 per cent., the indicated horse-power being the same in both cases, attributable solely to the foulness of the bottom. Under these circumstances, it would require double the power to attain the original speed.

As regarded the relative efficiency of the screw-propeller and the paddle-wheel, he believed, that either one, or the other, might be practically misapplied, to the extent of neutralising 30 per cent. of the engine power; and that erroneous conclusions were frequently arrived at, in consequence of such misapplication of the principles, or instruments, intended to be compared with each other. The extent to which conclusions, based on steam-shipping experiments, were liable to be delusive, might be judged of from the fact, that very few publicly promulgated reports of steam-ship trials contained even the elements of investigation, on which any sound judgment whatever could be formed, as to the merits of the practical result. And since the relative merits of different propelling instruments and means, such as the paddle-wheel, the screw-propeller, and the water-jet, of different kinds, and of different applications of the same principle, must, popularly, be a practical, rather than a theoretical inquiry, it followed that little could be done in this inquiry, unless the law was agreed upon, by which the dynamic results of the respective appliances might be judged of and compared. Subject, therefore, to the generally recognised law before referred to, he was enabled to state, that the highest index numbers of dynamic duty that had come to his knowledge, or had been credibly reported to him, had been the productions of the screw propeller; and this was confirmed by the fact, that on comparison of the indicated and effective powers of paddle-wheel and screw-propeller vessels, attached to a fixed dynamometer, the highest ratio of effective to indicated power, known to Mr. Atherton, had been obtained by the agency of the screw propeller.

The subject of high speed steam navigation, especially with respect to the mutual relations of speed and cost, had been fully inquired into in the second edition of his "Essay on Steam Ship Capability."[1] He therein showed, that the cost per ton weight of cargo, of performing long voyages, at high rates of speed, with steam-ships of ordinary magnitude, increased in such a rapid ratio as would scarcely be credited in discussion; but it was a subject illustrating the capabilities of large ships pre-eminently worthy of

[1] *Vide* "Steam Ship Capability." By C. Atherton. 8vo. London, 1845.

private study, on the part of all who were interested in steam-shipping affairs.

Mr. PHIPPS said, that the arguments adduced in the Paper under discussion were utterly at variance with all recognised principles. One point, in particular, he would advert to. The Author ignored, altogether, the effect of the friction of their immersed surfaces upon the speed of vessels. Mr. Phipps had calculated, as nearly as he could, from the data accessible to him, the number of superficial feet presented by the immersed portion of the hull of the 'Rattler,' a vessel of which all the particulars were perhaps more generally known than of most others. That vessel had an immersed surface of about 7,000 square feet, and according to the experiments of Beaufoy,[1] on the friction of immersed surfaces, at 10 knots per hour the friction was eight-tenths of a pound on every square foot, and at a speed of 11 knots per hour, the friction was very nearly 1 lb. per square foot. At the former speed and friction, the power absorbed might be taken as equivalent to 170 H.P. What could be thought, therefore, of a theory which, in the case of the above vessel, would entirely disregard a loss equal to 170 H.P., when the total indicated power of the engines amounted only to 428 H.P.? It was a well-understood principle in ship-building that, within given limits, when the length was increased power was economised; but to assert that this could be done without any limit, was, for the reasons above given, evidently absurd.

The importance of discovering the true resistance of vessels, moving through the water at different speeds, relative to which there were not at present any reliable data, could not be overrated. The experiments which had been made on this subject with the 'Rattler,' were inconclusive, inasmuch as the dynamometer applied to the end of the driving shaft of a screw vessel must show different and higher results than would be the case if the dynamometer was applied to the shaft of a paddle-wheel vessel of similar dimensions. His reason for thinking so was, that as the action of the screw neutralised, to a great extent, the current coming aft, and momentarily filling up the cavity left by the vessel's stern, the minus resistance would be thereby increased, and the pressure on the end of the screw shaft would be greater than the tension to which a cable would be subject, when applied to tow a similar vessel.

Mr. WIMSHURST said, ever since he built the 'Archimedes,' the first screw-steamer, he had been impressed with the paramount importance of giving fine lines to all auxiliary steam-vessels; in fact, that they should be as efficient under sails alone as under

[1] *Vide* "Nautical and Hydraulic Experiments, with numerous Scientific Miscellanies." By Col. M. Beaufoy. 3 vols., 4to. London, 1834.

steam. If so much power was required to obtain an increased speed, it was evidently important to get rid of all resistance arising from dragging propellers and stern-posts of a bad form through the water—which caused a loss equal to the cube of the velocity of resistance to a body passing through the water.

Mr. HUMPHRYS said he had accompanied Mr. Dinnen when the experiments with the 'Desperate' were made. Those experiments extended over a period of fourteen days, and it was unnecessary to say, that they had been accurately recorded, so far as the speed of the ship was concerned.

During the time that Mr. Humphrys held the appointment of Chief Engineer at the Woolwich Dockyard, he had many opportunities of measuring the power expended in propelling different vessels, at different velocities. Trials with the 'Retribution' paddle-wheel steamer, of 1,800 tons burthen, in July, 1850, showed that with four boilers, and 1,092 indicated H.P., a speed of 10·4 knots per hour was attained, whilst with one boiler, worked at the highest grade of expansion, and 226 indicated H.P., the speed was 6·22 knots. These results agreed very nearly with what would be deduced from the usually accepted rule. With a totally different class of vessel, the 'Onyx,' one of the paddle-wheel mail boats between Dover and Calais, with two boilers, worked to full power, and 533 indicated H.P., a speed of 13·16 knots per hour was realised; whilst with one boiler, and the steam at a low pressure, the indicated power was 158 H.P., and the speed was 8·6 knots. This, when worked out, still went to support the recognised theory. He might also mention the case of H.M.S. 'Desperate,' a screw-steamer, before referred to, which was tried in the River Thames, before being sent out to sea. With four cylinders, a speed of 10·76 knots was attained, with 891 indicated H.P.; whilst with two cylinders, the speed realised was 8·78 knots, with 391 indicated H.P.

The Author appeared to base his arguments, in a great measure, upon the reports of the trials of the French war-steamer 'Charlemagne,' in which the expenditure of coal, with two boilers, was 3,064 lbs., to propel the vessel at the rate of 8 miles an hour, and 5,733 lbs., when the speed was 10·9 miles per hour. He then proceeded to measure the power by the quantity of coals burnt. This, Mr. Humphrys believed, was very fallacious reasoning, as the quantity of coal burnt could not be taken as any index of the power exerted by the engines, unless they were working under precisely similar circumstances, which was not the case on board the 'Charlemagne.' During the trials with the 'Retribution,' before referred to, two sets of indicator diagrams were taken. Diagram Fig. 1 would be looked upon as a fair average expansion card. Diagram Fig. 2 indicated the state of the engines when working at

Fig. 1.

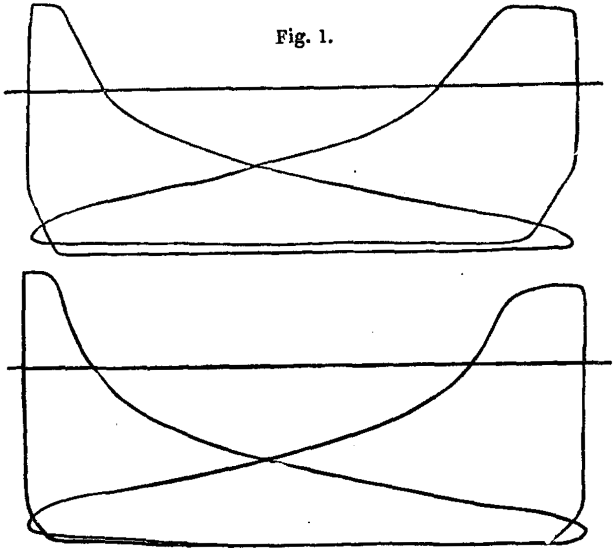
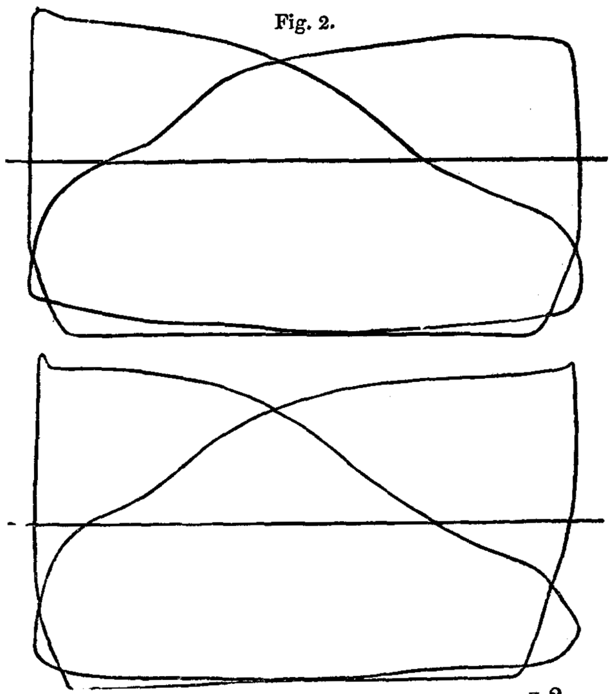


Fig. 2.



full power. In the former the quantity of steam used, measured by the diagram, was $6\frac{1}{2}$ cubic feet per minute, for each indicated H.P., and in the other, where as much steam was put into the engines as was desirable, it was 11 cubic feet, both being taken at atmospheric pressure. Yet, the boiler surface, in the former case, was 7·2 superficial feet, whilst in the latter, it was only 5·96 superficial feet, per indicated H.P., so that, taking the boiler surface as an index of the steam generated, there was a loss of fully 50 per cent. He would add, that fully nine-tenths of the advantage, supposed to result from working steam expansively in marine engines, was due to the reduced expenditure of power. A trifling loss of speed in the ship was not noticed, and all the economy which resulted from the reduced expenditure of power was attributed to expansion. The results of the trials of the 'Desperate' supported this view. When four boilers and four engines were worked, 5 lbs. of coal were burnt per indicated H.P. per hour: whilst with two boilers working the four engines expansively, 8 lbs. of coal were burnt per indicated H.P. per hour.

Mr. SAMUDA would offer a few observations, with the view of removing the impression which appeared to be entertained, that form had nothing to do with the speed of a vessel through the water. The 'Dart,' a London and Margate steam-boat, which was originally constructed like a sailing-ship, after running for some time, had a new bow added, by which, without any alteration in the engines, entirely in consequence of the reduction of resistance, her speed was improved at least 10 per cent. A better result was obtained, shortly afterwards, in the 'Magnet.' The original bow was at an angle of 42°, and in this state she had 134 feet of midship section immersed; when the angle of the bow was altered to 23°, she had 135 feet immersed. The speed in the former case was 10·02 knots, and in the second 11·75 knots an hour, being an increase in the ratio of performance of nearly 30 per cent. Another instance, still more marked, occurred last year, in a vessel called the 'Flying Fish'—one of the larger class of Government despatch boats. This vessel, with 1,166 indicated H.P. only attained a speed of 11·73 knots. That performance did not equal the expectations of the Admiralty authorities: and, without any variation in the other parts of the vessel, they added, not a new bow, but an elongated bow, 18 feet in length, in advance of the original one, to divide the water more freely. The result was, that with the same draught of water, an increase of velocity from 11·73 knots to 12·55 knots an hour was attained. The indicated H.P. was 100 H.P. more, but making all allowances for that, the ratio of performance was increased as 7 to 6. The 100 additional indicated H.P. would not advance the velocity of the ship more than one-tenth of a knot per hour, whereas the increase of speed was eight-tenths, showing seven-tenths as due to lessening the resistance. The screw, in fact, became a better propeller, and the decreased slip (in the improved performance) was exactly seven-tenths of a knot. He thought these facts were sufficient to remove the impression, that form had nothing whatever to do with the speed of a ship.

With regard to the question of the cube of the velocity being the real measure of the resistance, an examination of forty, or fifty vessels had induced the conviction, that there was no other way of measuring it. There was a point assumed in the Tables prepared by the Author of the Paper, which, if taken as a starting-point in the discussion, would lead to error, if the facts were dealt with by the same law. Every vessel in the Table was treated, as if the same coefficient applied to all forms and kinds of vessels. Now, it was well known, that for every vessel, a different coefficient was necessary. Thus, for H.M. Yacht the 'Fairy,' the coefficient was about 700, whilst for the 'Himalaya' it was 1,200, and yet these two had been treated by the Author as identical. Experience had shown, in all cases, that the resistance was nearly as the cube of the velocity, and that when a proper coefficient was adopted the speed might readily be calculated to within a quarter of a knot. Some experiments with four vessels, built on the same lines, although at different periods, and without any intention of comparison, yet agreed in a remarkable degree. The particulars of these vessels might be thus given:

No.	Midship Section.	Indicated H.P.	Miles per Hour.
	Sq. Ft.		
1	266	226	10·2
2	248	220	9·7
3	190	213	10·5
4	190	320	11·6

This showed, very nearly, the same ratio of performance throughout, and the vessel which had the highest velocity had the greatest amount of immersion, the screw working more efficiently.

Mr. RENNIE said, a comparison of the actual speed of two ships belonging to the Peninsular and Oriental Company, the 'Candia' and the 'Pera,' with the speeds calculated by two of the rules given in the course of the discussion, showed the following results:—

	CANDIA.				PERA.			
			ERROR.				ERROR.	
	Knots.	Statute miles.	Knots.	Statute miles.	Knots.	Statute miles.	Knots.	Statute miles.
Speed, Actual	11·93	13·7	..	..	12·55	14·4	..	..
Ditto by formula $V^3 = \frac{\sqrt{\text{H.P.} \times c}}{D^{\frac{2}{3}}}$	11·38	13·1	·55	·6	11·22	12·9	1·33	1·5
Ditto ditto $V^2 = \frac{\frac{2}{3}\text{I.H.P.} \times 100}{\text{Mid. Sect.}}$	11·28	13·0	·65	·7	11·28	13·0	1·27	1·4

The dimensions of the 'Candia' were, length 281 feet, breadth 40 feet, and depth 29 feet 6¾ inches. The engines were 450 nominal H.P. and 1,340 indicated H.P. The mean draught was 18 feet 4 inches, the area of the midship section was 523 square feet, and the displacement was 2,422 tons. The dimensions of the 'Pera' were, length 303 feet, breadth 42 feet, and depth 29 feet. The engines were 450 nominal H.P., and 1,414 indicated H.P. The mean draught was 18 feet 3 inches, the area of the midship section was 552 square feet, and the displacement was 2,792 tons.[1]

Mr. G. P. Bidder, V. P., said, it had been determined by mathematicians of the highest standing, that the resistance was as the square, and the power as the cube; and it was, therefore, useless to discuss, whether the actual friction was as the square of the velocity, and whether the resistance to a body moving in water was also as the square. The theory of rivers, and the movement of water in pipes, both showed, that allowance must be made for the

[1] The results of the trials of the 'Candia,' when first tested, and after being lengthened, subsequent to the discussion, 33 feet 6 inches amidships, by which the load displacement was increased about 470 tons, was conclusive as to the effect of lengthening:—

Date of Trial.	Draft of Water.	Length.	Displacement.	Weight on Board.	Revolutions of Engines.	Pressure of Steam.	Vacuum.	Indicated H.P.	Pitch of Screw.	Number of Blades.	Speed of Vessel.
1854: May 31.	18·6	281	2,520	650	36½	22	26½	1,672	20	2	12·651
1857: Aug. 12.	19·0	314·6	3,090	1,000	33	20	26	1,462	21	3	12·443

Thus with rather less indicated power, the vessel made nearly the same speed as formerly; and had the boilers been new and indicated the same power, it was believed that her speed would have been equal to, or even greater than on the last occasion; proving that it was not merely the displacement that must be taken into account in comparing vessels, but also its disposition.—G. R.

resistance due to friction. He calculated that the 'Himalaya' had an immersed surface of 18,000 square feet, and that this, at a velocity of 13 knots to 15 knots per hour, would absorb 800 indicated H.P., supposing that the bottom was perfectly clean and free from barnacles, &c. It was easy to contrive a formula which should give results nearly agreeing with the actual facts, at some one point over a long range of figures; and the error was less apparent, when the actual and calculated velocities were compared, than when the power was taken into account, as a variation of only 7 or 8 per cent. in the former case would cause a difference in the latter of 25, or 30 per cent. Nothing required greater care, knowledge, and skill, than the conduct of experiments on the friction of bodies moving in water. A large series of experiments of this kind, which had gained for their Author admission into the Royal Society, had been found to be incapable of analysis. The size of the vessel, and particularly its length, were undoubtedly of great importance for ocean navigation, as the vessel then acquired sufficient momentum to overcome the irregularities and undulations of the surface of the sea, which it must encounter.

PROFESSOR AIRY said, that many of his views on this subject had been anticipated in the discussion which had already taken place. He was much struck with the dangerous tendency of the experiments detailed in the Paper. In experiments to ascertain the resistance of bodies passing through fluids, and the amount of steam-power necessary to overcome that resistance, it was proper to separate the different parts of the experiment, and to confine one experiment to the variations of one element alone. He believed, that, up to the present time, there had not been a sufficient number of experiments to determine accurately, for the ordinary velocities of steam-ships, the relation of the resistance to the velocity of the ship; and he was confident, that anything which the Institution of Civil Engineers could do, to promote experiments with regard to the power of traction, (as shown, for instance, by a dynamometer on a tow-rope,) in relation to the speed with which the ship was drawn through the water, without any reference to the power of the steam-engine, or the consumption of coal, would be of the utmost value to practical science. There was a positive, mathematical, invariable relation between the resistance, and the power required to overcome that resistance; that was, if the law of resistance could be made out, as shown by the tension of a rope, and could be expressed by an algebraical formula, that formula must be multiplied by the velocity, in order to express the law of the power necessary to overcome that resistance. For instance, if the resistance was proportional, exactly, to the square of the velocity, the power necessary to overcome that resistance was exactly proportional to the cube of the velocity. That was a mathematical truth not admitting of the smallest modification. Whether the steam-engine was properly adapted to produce this power, and whether the consumption of coals was properly managed, were totally different questions, and were each the subject of different experiments; but, considering the complication of each of these questions, they ought never to be combined in one set of experiments. With regard to the screw, he might mention an idea which occurred to him some years ago, as tending, possibly, if followed out, to throw some light on the subject of the loss of power in the use of the screw, and the way in which that loss might be reduced. He took it for granted, that where a screw was used as the propelling power of a ship, there were three classes of loss of power; two of these were "slip" of different kinds, because the screw did not hold its place as if water were a solid element, like the wheels of a locomotive upon a railway; a third was the friction of the screw in the water. With regard to the slip of the fans of the screw in the water, if the different action of the screw, at different degrees of pitch, was considered, it would be found, that when the pitch was very low, the slip might be considered as mainly in a longitudinal direction of the spindle; and where the pitch was high, the slip was occasioned mainly by the water being carried in rotation. Hence it appeared to him, that something might be gained by obtaining a correct knowledge of the degree of motion given to the water in the two following cases:—one with such fans, as, when turned in the water, would not produce any endways motion—fans whose planes all passed through the line of the axis; and the other, in which there was not rotation, as when a disc surface was moved in the direction of the spindle. These might be taken as the extreme cases of the two degrees of slip which were combined in the screw—the one a rotary, and the other a longitudinal slip. But there was another circumstance, probably not inconsiderable in affecting the efficiency of the screw, as compared with the paddle-wheel; that was, the friction of the screw through the water. Considering the great speed at which the screw was turned, he thought that the friction through the water had considerable influence upon its power, and there was nothing analogous to it in the loss of power of the paddle-wheel.

Mr. GRIFFITHS said, the trials with the 'Flying Fish' at Portsmouth, showed that the form of the ship ought to be made suitable to the power intended to be applied. When tried on the 3rd of July, the following results were obtained:—

	Revolutions per minute.	Indicated H.P.	Speed in knots.
With full power . . .	74½	1106·06	11·603
„ ¾ „ . . .	68½	877·00	11·201
„ ½ „ . . .	59	576·00	9·923

Thus, when the power was doubled, there was only an increase of speed of 1·68 knot. She was then fitted with a temporary bow, to give a finer entrance, and again tried on the 16th of September, with the following results:—

	Revolutions per minute.	Indicated H.P.	Speed in knots.
With full power . . .	77	1309·00	12·572
„ $\frac{3}{4}$ „ . . .	68	918·72	11·150
„ $\frac{1}{2}$ „ . . .	60	660·18	10·120

Thus doubling the power gave an increase of speed of 2·452 knots, or just what was due to the cube of the extra power exerted, with the temporary bow, whilst no increase of speed was obtained at half and three-quarter power, and at full power nearly 1 knot extra was obtained.

In these trials it was proved, that there was considerably more resistance offered by the water to the blades of a screw, when set at an inclination towards the ship, than when at right angles with the screw shaft. The screw of the 'Flying Fish' had two sets of blades, one set being at right angles with the shaft, in the ordinary way, and the other at an angle of about 18° to the ship. In the first case the pitch was 20 feet 6 inches, the number of revolutions 75½ per minute, and the indicated H.P. 1281·8; whilst in the latter, the pitch was only 16 feet, the number of revolutions 77·3 per minute, and the indicated H.P. 1265, giving a result slightly in favour of straight blades. The steam-ship 'Dane,' of 40 H.P. and 500 tons measurement, had originally a screw of 10 feet 6 inches diameter, and 18 feet pitch, with three blades, each 3 feet 4 inches wide at the point, and 1 foot 10 inches at the root, when the speed obtained was 8·5 knots per hour. When a screw with two blades was applied, of the same diameter and pitch, but the points only 9 inches wide, and 3 feet at the root, the speed was 8·675 knots, all the circumstances being alike, excepting that the two-bladed screw made 6 revolutions per minute more,—partly due to the diminished friction and to the increased speed of the vessel. The screw of the steam-ship 'Augusta,' of 60 H.P., was 5 feet 6 inches diameter, and was originally 11 feet 3 inches pitch, when the number of revolutions was 110, and the speed was 6·385 knots. When the pitch was altered to 10 feet 3 inches, the speed was increased to 7·9 knots, the number of revolutions, and all the other circumstances, being the same.

Mr. J. E. M'Connell remarked, that no conclusion could be arrived at either from the Paper, or from the discussion upon it, as far as it had yet gone; nor had an exact rule, or reliable data of any description been produced, for the information and guidance of the Members. Great difference of opinion had been expressed, and the formulæ brought forward, for ascertaining the effect of certain proportions of vessels, and the relative forces necessary to propel them, at stated speeds, gave such different results, that it really seemed as if those who laid claim to a practical knowledge of the subject were incompetent to give any good rule, for determining the relative proportion of any one of the conditions of a steam-vessel. It was remarkable, that in a country which stood pre-eminent for its advancement in mechanical science, the application of steam to navigation was, as yet, imperfectly understood. As had been well remarked, what was required was, the proportion of the power disintegrated, that showing the amount used in propelling the vessel, expended in slip, by paddle, or by screw, and absorbed by the engines themselves. He quite agreed in the opinion, that the trials over the measured mile were of no value, either in point of comparative performance, or in consumption of fuel. He therefore proposed to direct attention to the results of the regular working of the Chester and Holyhead Railway Company's steam-vessels, running between Holyhead and Kingstown, a distance of 63 miles.

There were three vessels, named respectively the 'Anglia,' the 'Cambria,' and the 'Scotia.' They were built for speed; and, he believed that, when ordered, the builders of the ships and the makers of the engines were given to understand, that a test of their comparative merits, as to speed and economy of fuel, would be strictly applied. The arrangement for working these vessels was, that the time for performing the passage should be a constant, or as nearly uniform as possible; and that the variation of wind and tide should be met by more, or less pressure, the engines being worked expansively. The officers were subjected to censure, if the proper time was not kept, and the cause had to be fully explained.

The results of these trials were given in the annexed Table, which had been prepared by Admiral Moorsom, one of the Directors of the Chester and Holyhead Railway Company, to whom the excellent arrangements connected with the management of these vessels were due.[1]

He had been very anxious to elicit, from practical experience of these and other steam-ships at sea, some rule, or formula, by which could be determined the best proportions and forms of vessels, and the amount of power required to perform stated speeds.

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[1] *Vide* "Some Considerations on the Performances of Steam-Vessels." By Rear-Admiral Moorsom. Billing, Birmingham, 1856.

TABLE A.—Summary of Returns, showing the Performance of the Chester and Holyhead Company's Steam-vessels 'Anglia,' 'Cambria,' and 'Scotia,' and the Consumption of Coal between Holyhead and Kingstown, under certain conditions taken as standard tests.

Vessel's Name.	Time of Passage, 63 Statute Miles.	Rate per Hour, Statute Miles.	Proportion of Steam in Cylinder.	Vacuum by Diagram.	Pressure. By Diagram, per Sq. Inch.	Pressure. In Boiler, per Sq. Inch.	Barometer.	Hydrometrical Index.	Indicator H. P., 2 lbs. per Square Inch being deducted for Friction.	Coal Consumed in Running only. Per Trip.	Coal Consumed in Running only. Per Hour.
	h. m.			Inches.	lbs.	lbs.	Inches.			tons. cwts.	tons. cwts.
Anglia . . .	4 10 4 2	15·1 15·6	$\frac{24}{36}$ of Stroke	10·75	8·52	13·5	25·5	1·6	866·25	11 3·5	
	4 12 4 8	15 15·24	$\frac{23}{36}$ of Stroke	10·89	7·40	13·37	25·25	1·6	804·94	9 18·5	
	4 23 4 27	14·33 14·15	$\frac{20}{36}$ of Stroke	10·67	7·17	13·5	25·	1·57	776·39	9 7·5	
Mean average .	4 15	14·9		10·77	7·69	13·45	25·10		815·86	10 3·1	2 7·9
Cambria . . .	4 10 4 19	15·1 14·59	$\frac{27}{36}$ of Stroke	10·34	9·81	14·62	24·62	1·25 to 1	1114·47	12 9·5	
	4 12 4 16	15 14·76	$\frac{26}{36}$ of Stroke	10·97	7·43	14·87	26·62		969·73	9 10	
	4 16 4 24	14·76 14·31	$\frac{18}{36}$ of Stroke	10·94	5·05	14·75	26·75		795·99	8 9	
Mean average .	4 16	14·75		10·75	7·43	14·74	25·99		960·06	10 2·8	2 10·1
Scotia	4 4 4 0	15·49 15·75	$\frac{25}{36}$ of Stroke	10·7	7·87	11·33	26·5	1·82	1008·35	11 8·5	
	4 0 4 0	15·75 15·75	$\frac{22}{36}$ of Stroke	11·12	6·35	10·75	26·75	1·8	951·23	9 8·5	
	4 5 4 0	15·40 15·75	$\frac{19}{36}$ of Stroke	10·85	5·17	12	26·5	1·8	821·45	8 17	
Mean average .	4 1·5	15·64		10·89	6·46	11·36	26·58		927	9 18	2 6·6

The pamphlet by Admiral Moorsom, entitled 'Considerations on the Performances of Steam Vessels,' which had been printed for private circulation, bore so closely on the subject, that, with permission, he would make a few extracts from it.

The Admiral first remarked that, "one of the greatest obstacles to the scientific progress of naval architecture, is the absence of accurate observations at sea, that is, under the actual circumstances of vessels at their ordinary work."

Further he said, "The present incomplete position of the science of naval architecture has been brought especially under my notice lately, in consequence of proposals made by Government for the improvement of the mail and passenger communication between London and Dublin. It is proposed, that the passage between Holyhead and Kingstown should be made in three hours, between the lighthouses, a distance of 63 statute miles, and therefore at a speed made good of 21 miles an hour. At the request of the Companies to whom the proposals were made, certain firms offered to build vessels suited for the service. The vessels proposed, differed in displacement from about 1,550 tons to above 3,000 tons ; in nominal horse-power from 550 to 1,600 tons; in ratio of breadth to length, from 9·37 to 11·6 per cent. ; in draught of water to breadth, from 30 to 40 per cent. ; and in maximum speed to be attained in smooth water, from 22 to 25 miles an hour. Such varieties in a case apparently so simple, involving one condition only, namely, speed, illustrate clearly the want of rules founded on actual performance at sea. The question at issue is not the stowing of cargo, or of a large amount of fuel, or of carrying an armament, or of accommodation for a great number of persons, together with the accomplishment of a given speed: but of speed specially and alone, with as easy a motion in a seaway as the case admits of; for whatever the size may be that the speed requires, that size must be more than large enough for any probable amount of passengers under the circumstances."

With these great diversities in practice, it certainly did appear that something ought to be done, in order to obtain some reliable data on which to proceed. The suggestion, that the Government and the steam navigation companies should be requested to carry out a series of experiments at sea, was excellent, and would be productive of very beneficial effects, if there was a careful record of the performances, an exact compilation of them, and an honest publication of the recorded facts. It had occurred to him, that such experiments might be made with vessels like those belonging to the 'Cunard' and 'Collins' lines, running between Liverpool and New York.

The average consumption of coal on board the Holyhead steamers, for six years, including 1855, was at the rate of 5 cwt.

per hour under that given in Table A (page 347). The consumption during 1849 was at the rate of 2 tons 15 cwt. 98 lbs. per hour; but by the system subsequently introduced by Admiral Moorsom, a saving had been effected at the rate of 12 cwt. 60 lbs. per hour. It was carrying out on the passage between Holyhead and Kingstown, a system of comparison amongst steam-vessels, like that in use amongst railway locomotive engines, namely, the comparative amount of work done and of fuel consumed, for after all the chief point to be considered, was the economy of fuel, and the service performed. Quoting again from the Admiral's pamphlet:—

"Among the experiments made on the resistances to various forms of floating bodies, none are of more value than those of the late Colonel Beaufoy.

"Among those made to determine the performance of steam-vessels, the results established by MM. Bourgois and Moll are the most available for use. But the principle of Beaufoy's experiments is capable of a more extended application.

"The formula established by Bourgois and Moll, in 1848, and subsequently adopted in the paper printed by the Admiralty, in 1850, of which I have availed myself, and which records contain results of the trial of forty-four screw steamers, is useful so far as it gives a coefficient which is an exponent of the resistance offered by the form of the vessel, so long as the engines give out a relative uniform power.

"But as the 'absorbed power' varies in different engines, and in the same engines under different conditions, and as the 'slip' is affected by conditions of speed, and by the relative proportions of the wheel (or the screw), such a coefficient is not a measure of the resistance of the vessel under all circumstances, though it affords a fair medium of comparison of one vessel with another of equal displacement.

"This measure of the relative resistances of the same vessel under different conditions, or of different vessels under similar conditions, cannot be indicated by one coefficient only.

"Moreover, in the use of the formula in question, the value of the coefficient must, at present, be assumed arbitrarily at a guess in each case where it is required to determine the power, if the speed be given, or the speed, if the power be given; and it is only by collecting and classifying facts, in relation to different forms and sizes of vessels, and description of engines, that the application of the coefficient, in any given case, can be approximately reached.

"I am not aware that such collection and classification is yet commenced, except in private hands.

"I have been enabled, in some degree, to verify the experiments of Beaufoy on the resistance due to the mid-section of vessels, and the proportion of that resistance experienced by different forms. The basis of this verification is the resistance measured by the weight of the column of sea-water, whose base is equal to the area of mid-section, and height equal to that from which a body must fall to acquire the speed at which the area is impelled.

"The resistances, within my observation, lie within 10 to 12 per cent. of that deducible from this law, and reach to about 15 statute miles an hour."

The Admiral alluded to a verification of Beaufoy's formula applying to vessels attaining the speed of 15 miles per hour, and he says that "It is of importance to the subject under consideration, but it is not easy, to separate the elements composing the resistance opposed to the pressure on the piston.

"This consists of the resistance due to the form of the vessel, the slip of the wheel (or screw), and the power absorbed by transmission of the motion. This latter again is composed of the friction of the unloaded engine, the additional friction thrown on it by the load, and the retardation of the piston arising from an imperfect vacuum; or, in the case of non-condensing engines, by the full pressure of the atmosphere. The slip may, strictly, be considered as a part of the absorbed power, but it is desirable to treat it as a distinct element."

The formula of Beaufoy was given, but would scarcely apply to the practice as shown.

Table B (page 351) gives the resistances of some vessels as calculated by Admiral Moorsom. "On this Table many questions may be raised and much controversy, but the practical questions are two:—

"1st. Are the ratios of the breadth to the perimeter of the water-line, and the sine to the cosine of the angle of incidence of the water on the fore-body, together, an approximate measure of the rate of resistance compared with that due to the mid-section?

"2nd. Is the ratio of breadth to perimeter an approximate measure of the relative rate of resistance due to the form of the vessel, compared with that due to the mid-section? And is the ratio of sine to cosine of the angle of incidence of the water on the fore-body an approximate measure of the rate of resistance represented by the slip and the absorbed power? If these questions are answered in the affirmative, the results in the Table necessarily follow."

In that Table the vessels were distinguished by the letters A, B, C, D, E, F, G, H. In vessel A the ratio of breadth to perimeter per cent. was 6·5: of sine to cosine of angle of incidence per cent.

TABLE B.

Name.	Load Water-line. Length.	Load Water-line. Breadth.	Load Water-line. Draft.	Load Water-line. Area of Mid-section.	Load Water-line. Perimeter.	Load Water-line. Angle of Entrance.	Load Water-line. Displacement.	Ratios. Breadth to Perimeter per Cent.	Ratios. Sine to Cosine of Angle of Incidence per Cent.	Ratios. Resistance compared with that due to Midsection. Calculated per Cent.	Ratios. Resistance compared with that due to Midsection. Actual on Trial per Cent.	Proportions of Resistance. Due to Vessel per Cent.	Proportions of Resistance. Due to Slip per Cent.	Proportions of Resistance. Absorbed Power per Cent.	Proportions of Power. Due to Vessel per Cent.	Proportions of Power. Due to Slip per Cent.	Proportions of Power. Absorbed Power per Cent.	Actual Power on Piston in lbs.	Effective Power of Resistance. Calculated.	Effective Power of Resistance. Actual on Trial.	Speed, Feet per Minute. Calculated.	Speed, Feet per Minute. Actual on Trial.	Speed, Feet per Minute. Actual at Sea.	Difference of Calculated Speed per Cent. +	Difference of Calculated Speed per Cent. −	Coefficient of Performance.	
	ft.	ft.	ft.	sq. ft.	ft.	°	tons												lbs.	lbs.							
A	194	26·8	8·85	188	415	15·75	600	6·5	13·8	20·3	23	6·5	5·14	11·2	28·3	22·4	49·2	30182935	21270	23023	1372		1311	4·6		666·7	At sea.
B	198	27	9·5	230	422	15·5	750	6·4	13·6	20	22·5	6·4	4·9	11·24	28	21·79	49·8	35001630	26003	27027	1346		1295	3·9		689·2	
C	195	27·5	8·75	182	415	16	600	6·6	14	20·6	22·9	6·59	4·87	11·46	28·7	21·24	49·8	33863034	23730	24579	1427		1377·7	3·57		680·7	
D	300	40·25	13·75	393	638	15·26	1926	6·26	13·4	19·66	16	6·26	together 9·8 data wanting.		38·77	together 61·2 data wanting.		98340000	61416	87549	1601	1708·8			6·31	965·58	In smooth water.
E	144·6	21	4·83	71·5	308	16·5	168	6·8	14·5	21·3	21·17	6·8	7·36	7·5	32	34·6	33·25	12005400	8763	8876·5	1370	1352·56		1·2		713·6	
F	194·3	34·6	14·5	392	416	20	1323	8·3	17·84	26·14	21	8·3	3·34	9·33	39·3	16·4	44·2	30346800	30781	28737	986	1056			6·64	736·6	
G	210	40·5	15·25	517	451	22	2050	8·98	19·4	28·38	23·8	8·98	5·158	9·66	37·7	21·67	40·6	41091600	42774·8	44176·9	970	930·16		4·2		490·3	
H	176	48·5	21·3	750	390	31	2828	12·4	27·7	40·1	44	12·4	9·75	22	28	22	49·8	28997100	42800	44229	677·5	655·6		3·34		352·9	

13·8 : resistance compared to that due to mid-section 20·3 : actual on trial 23. The proportion of resistance due to the vessel was 6·5 per cent.; that due to slip was 5·14 per cent., and the absorbed power was 11·2 per cent.; this gave the whole resistance due to vessel, slip, and engines. That, as one instance, went far to show, that the formula laid down coincided very nearly with actual trial.

Mr. M'Connell was aware, that he was scarcely in order in reading such copious extracts; but he thought, that on a purely scientific matter of this kind, when a new and very important formula was introduced, on so interesting a subject, the Author's views should not be slurred over. He had only taken selected portions of the pamphlet, which bore directly upon the subject of discussion.

In answer to questions from Members through the President relative to the formula, which did not appear to be given in the pamphlet, Mr. M'Connell said, the proportions of the breadth to the perimeter were given in the Table, as were also other conditions on which the calculations were based. The Table spoke for itself, and he was sure the meeting would not wish him to go through the whole calculation. As a starting point, there was Beaufoy's formula, on the resistance due to the mid-section of vessels; and all engineers were, he believed, well acquainted with the formula which had been alluded to.

Mr. M'Connell observed, that in all discussions on this subject he had listened with great attention, hoping to obtain some practically useful data, or formulæ, but none were offered. He begged to suggest that Mr. Scott Russell should favour the Institution with his formulæ, and also that other ship-builders and engineers should do the same, as it was believed that they all differed from each other. Mr. M'Connell would then be ready to compare the formula he had advanced with theirs, in order to ascertain which was the best for general practical guidance.

Mr. J. Scott Russell stated, that the usual formula of Colonel Beaufoy, $R = a\,w\,\frac{v^2}{2g}$ only gave the resistance to a boat with a square head; but what was wanted was the reduction upon this, for a certain amount of sharpness of bow, for different sizes, shapes, and proportions of vessels. With a semicircular or round head, which was nearer to the form of the bows of sailing ships, it had been found, that the resistance was only two-thirds of the amount derived from the above formula; and with an elliptical head it was still less. Formerly the duck's breast had been regarded as the most beautiful form of bow, but, by making the bow finer, the resistance had been gradually brought down to one-fifth, one-sixth, and one-seventh of the total resistance given by the formula, as the result of a long course of experiments. He believed the quantity of engine power to propel a large vessel through the water was now, in some cases, as low as one-twelfth; ship-builders having endeavoured, during the last twenty-five years, to diminish the coefficient by means of improved forms.

The theory in the Paper was, that the shape of a ship had nothing to do with the speed. He had an opportunity of trying this experiment, when he had built two vessels of nearly identical dimensions, to which he had given the same midship section. Both these vessels were 15 feet wide; one was 144 feet in length—the other 100 feet; one had 42 square feet of midship section—the other 43 square feet. Each vessel had engines whose cylinders were 30 inches diameter, and 2 feet 6 inches stroke, each having developed exactly the same amount of power. The one which attained the greatest speed made 36 revolutions per minute, whilst the other made 38 strokes, and yet the vessel was propelled at a slower rate. The result was, that one vessel had a speed of 10·08 knots per hour, whilst the other attained a speed of only 8·88 knots. In this case displacement, midship section, and everything were similar, excepting form and length, and these caused the difference in the performances. But it might be said, that the difference was accounted for by the difference of length, and such had been his opinion also; therefore he determined to make a second experiment upon two vessels of nearly identical length. These two vessels were built of the respective lengths of 190 feet and 186 feet, their breadths being equal: the engines had cylinders of 48 inches diameter, with 4 feet 6 inches stroke. One engine made steadily 39 strokes per minute—the other from 38 to 40 strokes. The speed attained by the former was 15·03 knots, whilst that of the latter was only 11·32 knots. The difference between the two vessels in this case consisted chiefly in the shape;—the other and minor elements being much in favour of the slower vessel; for instance, the faster vessel had 124 feet of midship section, whilst the slower vessel had only 71 feet of midship section, to drag through the water. The faster vessel drew 6 feet 8 inches of water, whilst the slower vessel drew only 2 feet 10 inches of water. In this case the difference of length was only 4 feet, yet a radical difference in shape only reduced the velocity, with equal power, from 15 knots to 11 knots per hour. In the case of a vessel built with bow and stern alike, so as to travel either way, when going with bows first, the speed was 10·88 knots, and when running the other way it was only 9·64 knots; this latter case was another criterion experiment on the effect of shape alone.

The ship-builders had been accused of not knowing their business; whilst it was said, that the engine-builders performed their part of the work perfectly. That comparison was most unjust to the ship-builders, who had made a vast number of useful experiments, had devoted a great deal of pains and study to their profession, and had in reality got possession of nearly all the practical facts which they were accused of not knowing. The first step which a shipbuilder took before he constructed a vessel, was to find the area of the midship section (a in the formula). The influence of the midship area was this;—an engine in a ship was required to make the hole in the water through which the ship had to pass, which might be compared to the excavation of a long canal. The first calculation then was, how large a canal the ship was required to open for itself—how much water it had to displace? The next question was—how much power had the engine to exert to displace this water from its path? Then $\frac{v^2}{2g}$ was the measure of this power, and w being the weight of water an inch in depth, the total weight of water was equal to $a\,\frac{v^2}{2g}\,w$. This well-known formula went no farther; it omitted the one element which all the formulæ he had hitherto seen also left out, and which he had hoped Admiral Moorsom's pamphlet would have given. That was the reduction, necessary for a certain degree of fineness of shape. But almost all shipbuilders, in calculating the resistance which their vessels opposed to the water, only took a fraction of the result derived from the formula.

He agreed in the suggestion of making exact experiments, on a large scale, to ascertain the value of this fraction in ships of different forms. He ventured to repeat the hope, that the Council would not think it inconsistent with their duty to the profession to endeavour to get a few good, reliable, practical results, showing the value of this fraction for different sizes, shapes, and proportions of vessels. He had made most of these experiments, and on some future occasion he should be happy to communicate them to the Institution.

For the present he would content himself with saying, that he had ascertained, that at 10 knots per hour, with a vessel of proper form, of 1,500 tons burthen, the head resistance of a ship could be reduced to 50 lbs. per square foot. He had also ascertained how much a similar vessel could be propelled with by engine power alone, including the loss due to the working of the engines, and he had found that, whilst the direct resistance to a ship going at 10 knots per hour was only 50 lbs. per square foot of midship section, including all loss from communication by paddle-wheel, air-pump, and other sources, except the slip, this resistance was not more than 65 lbs. per square foot of midship section. Thus they could calculate confidently, to within a quarter of a knot, as he had done for years past with his peculiar shape of ship, the amount of steam-power necessary to propel a given ship, at a given speed, and there was a shape for every speed; as for instance when a speed of 10 knots per hour was desired, he provided for 50 lbs.[1] per square foot of midship section, for the resistance of that ship, and when he had to overcome the resistance of the machinery also, he made that up to 65 lbs.[1] per square foot. These were the principles upon which he calculated. Perhaps the experience of other ship-builders led them to different results, which he should be happy to learn during this discussion. Though experimenting in that way, the ship-builders would still be thankful to those who could give them information. But while he confessed they did not know all that they desired, he did not thereby plead guilty to their knowing nothing at all upon the subject.

Mr. HAWKSLEY stated, it was quite possible, in the present advanced state of hydraulic science, to calculate with any desirable degree of accuracy, the value of the resistance which a steam, or other vessel would have to overcome, when moving through water at any given speed. The resistance consisted of two parts; the one well recognised under the somewhat obscure title of "the resistance to the immersed area of the midship section;" the other as yet scarcely admitted, though not less important, might be designated "the surface, or frictional resistance."

The midship resistance, considered without reference to the angular figure of the bow, or stern, was manifestly measured by the impulse of a stream of water having the velocity of the vessel upon a plane surface placed perpendicular to its path. This impulse was found, by experiment, to vary under different circumstances, from a value equal to the pressure of a column of water of twice the height due to the acquired velocity, down to a value equal to the height due to the acquired velocity. The latter measure would most probably apply to the resistance encountered by a sea-going steamer.[2]

Now, taking the area (a) of the midship section in square feet, the velocity (v) of the vessel, in lineal feet per second, g the accelerating force of gravity $= 32\frac{1}{6}$, and the weight of a cubic foot of sea water at $64\frac{1}{3}$ lbs. avoirdupois, and calling the resulting pressure (P), there was given,

$$P = \frac{v^2}{2\,g}\,a \times 64\tfrac{1}{3} = v^2\,a.$$

The surface resistance of water moving in contact with iron he

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[1] These figures, 50 lbs. and 65 lbs., are *gross* resistance, and include friction of skin. If friction of skin be deducted from these results, the remainder due to midship section comes down to about 25 lbs. *nett*, or $\frac{1}{12}\,a\,\frac{v^2}{2g}\,w$; *i. e.* $\frac{n}{m} = \frac{1}{12}$, being a difference of 6 to 1 in favour of the shape Mr. Russell used, over the old circular bow.—J. S. R.

[2] *Vide* Experiments of the French Academicians.

had ascertained with great care, and had found it amount to 25 ounces per square foot, with a velocity of 15 feet per second, whence, as this resistance varied exactly as the square of the velocity, it was very easy to calculate the retarding pressure (p) in lbs. of which it was the cause, when operating upon any area (s) of immersed surface by the very simple formula,

$$p = \frac{25}{16}\left(\frac{v}{15}\right)^2 s = \frac{v^2}{144} s.$$

But the value of (P) was modified by the respective angles made by the bow and the stern; calling the former (θ) and the latter (θ_1), then

$$P = \frac{1}{2} v^2 a \left(\sin^2 \frac{\theta}{2} + \sin^2 \frac{\theta_1}{2}\right).$$ [1]

The total resistance R to motion was therefore

$$P + p = R = \frac{1}{2} v^2 a \left(\sin^2 \frac{\theta}{2} + \sin^2 \frac{\theta_1}{2}\right) + \frac{v^2}{144} s.$$

And if, as very commonly happened, the velocity (V) was given in statute miles per hour, there would be obtained by making

$$v = \frac{5280}{3600} V = \frac{22}{15} V,$$

$$R = 1 \cdot 08\, V^2 a \left(\sin^2 \frac{\theta}{2} + \sin^2 \frac{\theta_1}{2}\right) + \frac{V^2}{67} s.$$

Moreover, if it was desired to know the effective horses power (H) requisite to overcome this aggregate resistance, there was deduced first

$$\frac{5280\, R\, V}{60 \times 33000} = \frac{R\, V}{375},$$

and thence

$$H = V^3 \left\{\frac{a}{347}\left(\sin^2 \frac{\theta}{2} + \sin^2 \frac{\theta_1}{2}\right) + \frac{s}{25125}\right\} \text{ - - - A}$$

Also similarly

$$V = 29 \left(\frac{H}{72\ a \left(\sin^2 \frac{\theta}{2} + \sin^2 \frac{\theta_1}{2}\right) + s.}\right)^{\frac{1}{3}} \text{ - - - B}$$

Mr. Hawksley further stated, that in these terms the formulæ

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[1] Theory assigns to the resistance of a moving plane inclined to its path at any angle θ the ratio of sin. $^2\theta$; experiment on the contrary affords a much higher result. It must, however, be remembered that experimental results have hitherto been complicated with the resistances arising from surface friction and the friction of the apparatus employed. This equation is capable of being expressed in another form, in which the second term within the paranthesis becomes negative, and corresponds to the minus pressure of some authorities.—T. H.

had been repeatedly compared with the actual performances of sea-going vessels of known power, magnitude, and figure, and so far as his experience had yet gone, it enabled him to place his deductions before the Institution with perfect confidence in their general accuracy and practical applicability. He thought that the formulæ would, in point of fact, afford results within 5 per cent. of actual experience. He also considered it was quite useless to attempt equations for curved forms, nor was it necessary to do so, as by dividing the immersed solid into four parts, by five equidistant planes taken parallel to the load water line, and calculating each part for three, or more angles, formed by the intersection of tangents to the respective curves of the bow and the stern lines, any required degree of exactitude might be obtained. In general, with regard to sharp vessels, a single calculation would be sufficient for ordinary practical purposes, and especially so after a little experience had been gained in estimating the angles at the head and stern capable of approximating to the results of curves.

In applying the formulæ, it was however requisite to bear in mind, that the effective horses power was in the case of large vessels about one-fifth part less than the indicated horses power, and also that in fresh water the resistance was somewhat less than in sea water, except in the case of confined channels, when it became greater than in the open sea.

Suppose it were wished to predetermine the speed of a vessel of nearly the magnitude and power of the 'Atrato,' and laid down on the following data:—

Indicated horse-power	=	3000
Effective horse-power = $\frac{4}{5}$ths indicated H.P.	=	2400
Beam	=	40 feet.
Immersion ($\frac{2}{5}$ths of beam) . .	=	16 ,,
Midship section	=	512 ,,
Slant length of bow to beam[1] . .	=	$2\frac{1}{2} : 1$
Midship length to beam . . .	=	$2\frac{1}{2} : 1$
Slant length aft to beam[1] . . .	=	$3 : 1$
Total length to beam . . .	=	$8 : 1$
Surface (assumed)	=	12800 feet.

$$\text{Then } V = 29\left(\frac{2400}{72 \times 512 \times \left(\frac{1}{25} + \frac{1}{36}\right) + 12800}\right)^{\frac{1}{3}} = 15\tfrac{2}{3}$$

miles per hour. The 'Atrato' was stated by the Author of the Paper to have attained in fresh water a velocity of 16 statute miles per hour over the measured mile.

Again, given with the same general proportions, a beam of 80

[1] The Slant length may be taken to be the length in contact with water.—T. H.

feet and a required speed of 18 miles per hour, to find the effective horse-power. In this case

$$H = 18^3 \left\{ \frac{2560}{347} \left(\frac{1}{25} + \frac{1}{36} \right) + \frac{51200}{25125} \right\} = 14{,}327 = \text{the}$$

effective H.P., or about 4500 nominal H.P.; but if the speed were to be reduced to 15 miles per hour, then the effective horse-power need not exceed 8264, or about 2500 nominal H.P., estimated at a mean of the present irregular, uncertain, and inconstant practice of computing the nominal capability.

The formulæ also showed, that the employment of an excessive length, or sharpness of bow was in most instances to be deprecated, and especially so where the stowage of cargo, or even the stowage of a large quantity of coals for a long voyage was an important object, for it must be obvious, that in many instances, the surface resistance, represented by the second term of the equation, might increase faster than the midship resistance represented by the first term of the equation, diminished, and indeed, in the example before the meeting, it would be found, that the surface resistance (a resistance which had hitherto been little cared for), was enormously greater than the midship resistance; indeed in many instances, this resistance was three, four, and even five times greater than the midship resistance.[1] The equation, also, pointed very distinctly to the value of magnitude. In vessels of a similar figure the amount of cargo stowed would be as the cube of the square root of the midship section, or as $a^{\frac{3}{2}}$, while the surface and midship resistances would each be as a only. The enormous expense attending high speeds was also indicated, as both descriptions of resistance involved the employment of a mechanical power, increasing as the cube of the maximum velocity, and an expenditure of fuel, increasing as the square of the velocity to be maintained in the transit between any two given ports. Hence the economy of steam navigation was dependent mainly on four elements,—

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[1] It is worthy of observation, that as respects sharp vessels the speed may be approximately determined, without any direct regard to the midship section, by the very simple formula $V = 27\left(\frac{H}{s}\right)^{\frac{1}{3}}$; and as ($s$) frequently approaches the rectangle of the breadth (b) and the length (l), this becomes (approximately) $V = 27\left(\frac{H}{bl}\right)^{\frac{1}{3}}$, and therefore roughly $H = \frac{V^3\,bl}{20{,}000}$. Thus if a sharply-built channel steamer be 200 feet long and 30 feet broad, and have two engines each of 60 nominal H.P., the total indicated power being about 500 horses, and the real, or effective power being about 400 horses, then, because $27\left(\frac{400}{30 \times 200}\right)^{\frac{1}{3}} = V$, a speed of about 11 statute miles per hour may be anticipated.—T. H.

1st. A sharp, but not excessively fine, entrance and run.
2nd. A moderate speed, regard being of course had to the special requirements of the service.
3rd. A considerable magnitude.
4th. A clean bottom, because the quantity s must be increased by an addition of the surfaces presented by weeds, barnacles, and other adhering substances.

Nothing had yet been said of the rules which ought to regulate the form of the after part of the vessel. It was, however, plain that as the same laws governed both the escape and the return of the water, the after part of the vessel should, so far as regarded the immersed portion, be as nearly as other more important considerations would permit, a duplicate of the bow, when the entrance was properly formed. But it was not necessary, except as a matter of taste, to employ complicated curves of contrary curvature in constructing the entrance and the run; indeed, in a long vessel, the lines of the bow and run might be, for considerable lengths, perfectly straight and tending very distinctly to the angles θ and θ_1, and these lines might be rounded off at each end with circular arcs of contrary curvature, without thereby sensibly affecting the performance of the vessel. It was also obvious, that the best way of obtaining both length and capacity, with a minimum resistance, was by the insertion of a parallel, or nearly parallel, piece in the middle of the vessel. It might likewise be remarked, that those lines which were considered to confer the greatest amount of beauty upon a vessel's hull, were all near approximations to the lines which would result from the intelligent study of the formulæ; and it might be further observed, that as regarded the power and speed of a vessel, it was by no means objectionable to employ a transverse section approaching to a rectangle, thereby obtaining a capacious hold, great buoyancy, and much stability. In strict theory the bow and stern lines of a vessel ought to be each formed of two equal and contrary parabolas, having a common tangent at their points of junction, and their vertices at the bow, the stern, and amidships respectively, but in practice considerable departures from the theoretical law might be made, without affecting the performance of the vessel in any very appreciable degree.

If a naval constructor wished to be particularly safe, with respect to the amount of power to be put on board, Mr. Hawksley would recommend the substitution of $\frac{a}{174}$ for $\frac{a}{347}$, in the formula A; and if anxious not to overstate the velocity, the substitution of 144 a for 72 a in the formula B. These altered terms, however, represented the most extreme values which any theory, or any experiment had assigned to the midship resistance; and after all did not, in ordinary cases vary the resulting velocity so much as a twentieth part.

Mr. PHIPPS could not concur in the assumption, that the resistance per square foot in the interior of a pipe was the same as on the outside of a ship; in fact, he had arrived at an exactly contrary conclusion. His attention was first called to the subject, when making some calculations to check the data given in Mr. Leslie's Paper, "On the Flow of Water through Pipes."[1]

In that Paper Mr. Leslie computed the actual gradients of the pipes, in several large examples, by dividing the length by the total height of head. The gradients thus obtained gave an easy mode of calculating the friction of the water in the pipes. It was only necessary to divide the total weight of water in the pipes, by its amount of gravity down the plane, which constituted the total moving power; and then to divide this quantity by the whole internal superficial area of the pipes, when the friction, or resistance per superficial foot, would be obtained. In this manner Mr. Phipps found that, at a velocity of 12·2 miles per hour, equal to 17·9 feet per second, the friction amounted to 2 lbs. upon each square foot, whilst according to the admirably-conducted experiments of Beaufoy,[2] the friction on the side of a ship at the same speed, was only 1 lb. on the square foot. As a further proof of the probable correctness of his deduction, he mentioned that, if the friction per square foot on the side of a ship was equal to that in a pipe, the power lost by friction in the case of the 'Rattler,' previously alluded to, would be equal to 340 H.P. out of a total power of 428 indicated H.P., leaving only 88 H.P. for overcoming all the other resistances.

Mr. HAWKSLEY said he was well aware of Mr. Leslie's experiments, which were all made on small pipes, but he did not draw the same inference from them. He had calculated the resistance in a pipe of 12 inches diameter, and in a pipe of 100 inches diameter, and found they both gave, as might have been expected, the same measure of resistance. At a velocity of 15 feet per second, the resistance was 25 ounces to the square foot. If the radius of a pipe was made indefinitely large, the side became, for any short arc practically straight, and it was therefore manifest that it was immaterial, as regarded the measure of the resistance, whether the water was outside, as in a ship, or inside, as in a pipe. He intended to institute a set of experiments, for the express purpose of clearing up the existing difficulties, with respect to the resistance of fluids acting by impact, on plane and curved surfaces,

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xiv., p. 302.

[2] *Vide* "Nautical and Hydraulic Experiments, with numerous Scientific Miscellanies." By Col. M. Beaufoy. 3 vols. 4to. London, 1834.

which, when completed, he would place before the Institution. These might lead to some modification of his present views, but he thought not to any important extent.

Mr. Bramwell wished to call attention to a remark which had been made, that a great portion of the apparent economy of working marine engines expansively resulted from the reduced power which was exerted. That position would be generally agreed to, but the subsequent statement, which induced the opinion that working steam expansively was a costly process, must be carefully examined, before it could be admitted, and was suffered to go forth to the world, uncontradicted, and to a certain extent sanctioned by the Institution. The fact stated was, that in the trials of the 'Retribution,' whilst the amount of steam used, when working expansively, was only $6\frac{1}{2}$ cubic feet, and 11 cubic feet, when using full power, yet the consumption of coals was 8 lbs. per indicated H.P. per hour in the former case, and 5 lbs. per hour in the latter. Thus with about 60 per cent. less steam, the coals consumed amounted to 60 per cent. more.

With regard to the friction of vessels passing through water, a curious experiment had been tried upon a boat between New York and Perth Amboy, by blowing air along a flat bottom externally, and preventing it from escaping laterally by slight keels, or ribs. He had seen the boat at work, and had been told, that when the pumps were thrown out of gear, the boat lost speed. It was said, however, that had the power employed to work the air-pumps been applied to the paddle wheels, a better result would have been obtained.

Mr. Humphrys said, the conditions in a marine engine were not the same as in land engines, whether stationary, or locomotive. A record of the performances, for three or four years, of H.M. paddle-wheel steamer 'Fury,' of 515 H.P., showed that, if the coal burnt and the distance run were alone considered, a favourable conclusion would be arrived at, as to working expansively; but the question now was, the quantity of fuel consumed per horse-power, not the distance run with a given quantity of coal. It had not occurred to the engineer in that case, to see what the power cost. As, however, he had given the mean pressure upon the pistons and the number of revolutions per minute, Mr. Humphrys had been enabled to calculate the consumption of coal per horse-power per hour, and this he had added to the following Table, giving the results of the performances alluded to:—

—	Coal consumed.		Distance run per Day.	Distance the Coals would last.
	Per Day.	Per H.P. per Hour.		
	Tons.	Lbs.	Statute Miles.	Statute Miles.
Full power . . .	50	3·97	264	2,112
1st grade of expansion	40	4·24	240	2,400
2nd ditto	36	4·79	222	2,466
3rd ditto	33	5·46	211	2,555
4th ditto	28	5·57	190	2,698
5th ditto	22	5·8	155	2,790
6th ditto	19	7·53	130	2,730
7th ditto	15	8·87	110	2,926

In a pamphlet by Capt. W. Ramsay, R.N., there were given the performances of H.M.S. 'Terrible' in her early days. She was a very fine vessel, and had a pair of engines of unquestionable efficiency. The following results (except the coal consumed per H.P. per hour) were recorded in a tabular form:—

—	Indicated H.P.	Coal consumed.		Speed.
		Per Day.	Per H.P. per Hour.	
		Tons.	Lbs.	Knots.
Full power . . .	1,850	100·5	5·07	12·8
1st grade of expansion	1,640	76·0	4·33	
2nd ditto	1,400	68·0	4·53	
3rd ditto	1,200	58·0	4·51	
4th ditto	1,000	51·0	4·76	
5th ditto	800	47·1	5·54	
6th ditto	650	44·75	6·42	9·8

These statements accorded with his own observations in a great number of cases. In fact, he had never found an instance in a steam-boat, where the cost of the power was less, when working expansively, than it was when working full power. The moment a marine engine began to work expansively, beyond what was due to the set and lap of the slide, the speed of the piston was reduced, and an important element in obtaining economy in working steam expansively was lost.

The 'Terrible' was a case of large engines working moderately. He would now give a case of comparatively small engines working hard. The 'Llewellin,' of 350 nominal H.P., when exerting her full power of 1,800 indicated H.P., consumed $3\frac{3}{4}$ tons per hour, or 4·6 lbs. per H.P. per hour, being a marked difference in favour of the small engines worked up to full power. Again, the 'Rosamond,' of 280 nominal H.P., when exerting her greatest effort of 492 indicated H.P., consumed $4\frac{3}{4}$ lbs. of coal per indicated H.P. per hour; but when working only to 168 indicated H.P., she consumed 7·9 lbs. of coal per H.P. per hour.

In marine engines, the attempts hitherto made for realising the benefits to be derived from working expansively had not been attended with adequate success. He believed that the loss, when working at a high degree of expansion, arose to a great extent from the condensation over the extended surfaces to which the steam was exposed, as only indifferent means were adopted for keeping up the temperature, and thus there must necessarily be a loss of mechanical effect. In the case of the 'Retribution,' before alluded to, there was a cylinder 72 inches in diameter, with a length of stroke of 7 feet, making when the indicator card, Fig. 1, (p. 339) was taken, eight to nine strokes per minute. Looking at the speed of the piston, and the vast amount of material to which the steam was exposed, without any means for keeping up its temperature, he was not surprised that three-fourths of the steam was condensed, without producing the effect on the machinery. In a large stationary pumping engine there was a mere breath of steam at the top of the stroke, and during the time this steam was giving out its power, the piston was travelling at an immense velocity; whereas, in a marine engine, there was a much slower action of the piston. In the land engine every means was taken to keep up the temperature of the steam, throughout its entire course, and if that was not done, much of the mechanical effect was lost.

The area of fire-grate might be received as an approximate index of the coal expended. In the 'Asia,' one of Cunard's line, the fire-grate to supply steam for one indicated H.P., when the engines were worked at $14\frac{1}{4}$ revolutions per minute, exerting 1,850 H.P., was ·234 of a square foot; whilst in the 'Garland' Dover Mail Packet, working to five times her nominal power, the fire-grate surface was ·198 of a square foot per horse-power.

It had been stated by a high authority, that "an engine worked under its force yields much more power, in proportion to the coal expended, than when worked to its full power." Now, Mr. Humphrys contended, on the contrary, that a marine engine, as now generally made, and as they were made at the time that statement was advanced, gave out the greatest amount of power, per coal expended, when exerting its utmost effort. His impression was, that the loss from working expansively in marine engines, arose from not observing the conditions necessary to realize the benefits of expansion. He was prepared to admit the value of it. But there would always be a difficulty in marine engines, because the load was uniform, whilst in land engines the load was accommodated to the power developed, and the full speed of the piston was thereby always maintained.

Mr. Andrew Henderson differed entirely from the views of the Author of the Paper, which he understood to be, that the area of the midship, or the largest transverse, section was the only element of resistance, and that the form of the vessel had little or nothing to do with the question of speed. He considered, on the contrary, that form and displacement were the principal elements, though there were others which he had endeavoured to eliminate. The weight of cargo a ship would carry would be represented by the displacement, but not by the midship section.

He had collected, for a number of years past, the particulars of the performances of different vessels, and the archives of the Institution now contained, in a tabular form, the records of the dimensions, proportions, tonnage, draft, displacement, area of midship section, weight, and other elements of resistance, of about one hundred vessels, together with the dimensions of the engines, the nominal horse-power, and the speed realized. He hoped that, by the co-operation of the Members, these records would be still greatly augmented. Ten years ago, he had brought the subject of 'Ocean Steam Navigation' before the Institution;[1] and again, in 1853, he had presented a Paper 'On the Speed and other Properties of Ocean Steamers, and on the Measurement of Ships for Tonnage.'[2] The question had also been discussed at the Society of Arts, and latterly at a meeting of the British Association at Dublin, where Mr. J. R. Napier contended, as did the Author of the present Paper, that the area of the midship section was the principal element of resistance, and proposed to use the formula $\frac{V^2 \text{ mid-sect.}}{\text{Ind. H.P.}}$, for ascertaining the comparative merits of vessels, by their coefficients, or index numbers, in place of the formula $\frac{V^3 D^{\frac{2}{3}}}{\text{Ind. H.P.}}$ used in the trials of H.M.S. 'Rattler.'

The difficulty of obtaining sufficiently detailed information, as to the performances of vessels at sea, was so great as to prevent any correct general law being at present established. The most complete series of details of this nature which he had yet obtained, was of the performances of the steam ships of the Peninsular and Oriental Company, for six years, while performing mail service, over a distance of 1,500,000 miles. The result showed at least 10 to 15 per cent. less speed than had been expected of them.

The Admiralty had been applied to for a return of the dimensions, displacement, draft, and indicated horse power of certain of the vessels in the Royal Navy, but the reply which had been given was, that the information had better be obtained from the mercantile marine. He had just received a tabulated statement of the results of the trial trips at the measured mile of thirty of the

[1] *Vide* Minutes of Proceedings Inst. C. E. for 1847, vol. vi., pp. 484 to 495.
[2] *Vide* Minutes of Proceedings Inst. C. E. for 1853-4, vol. xiii., pp. 1 to 63.

newest vessels belonging to the Peninsular and Oriental fleet, comprising the displacement, area of midship section, indicated horse power, and speed realized, and these he had embodied in a Table. In this table he had also given the index numbers, or coefficients of displacement and area of nine of these ships, calculated by both the formulæ given above; but the elements of the calculation being the results of test trials in smooth water, would vary when in a sea way, or on a long voyage, where the quantities were constantly changing.

The anomalies of the present system of tonnage measurement and registration were likewise exemplified in the Table, which was only submitted as an approximation to the desideratum of a uniform system of recording facts, of the performances of steam vessels at sea, under all circumstances.

A closer test of the relative qualities of vessels could be obtained by recording on the log, the indicated horse power from diagrams taken daily during the voyage, and at the same time the displacement, area of midship section, and mean draft of water. The mean of these coefficients, taken daily, at the end of the voyage, would afford a fair average of the qualities at sea; in the same way that the general average speed of the contract steamers was calculated from the Post-office returns, as shown in the Table, from which it appeared that the 'Haddington' averaged a speed of 8·154 miles per hour over 114,240 miles run, and the 'Hindostan' a speed of 9·195 miles per hour over 33,320 miles run. The mean draft, displacement, and area of midship section could be ascertained at the exact time of taking the indicated horse power and speed, by a pipe, or water gauge, through the keel about the middle of the length; a scale of displacement, and area of midship section furnished by the builder, or surveyor, being attached to the pipe.

Mr. R. Armstrong said, the immediate object of the Paper under discussion was, "An examination of the circumstances that appeared to limit the maintenance of higher speeds in deep-sea navigation." He implied from the proposition of that subject by the Institution, that the necessary requirements were not generally understood.

For the advancement of naval architecture, and the progress of steam transport economy, it was necessary to have the power of discriminating between good and bad vessels, of telling whether the engine was doing its assigned duty, and whether the vessel was fulfilling the requirements for which it was designed, and of reducing the necessary requirements, for any velocity, to a simple mathematical calculation. As a proof that the necessary requirements were not understood, the 'Parana,' 'Magdalena,' and 'Orinoco,' belonging to the Royal West India Mail Company, were adduced. When increased velocity was obtained by that Company, it was only by an immense increase of power. And in all cases where greater velocity had been obtained by the same nominal H.P., it had been due to the superior effectiveness of the engines.

He asserted, that the power of elimination was concentrated in the proposed formula

$$V^2 = \frac{\frac{2}{3}\ \text{I.H.P.} \times 100}{\text{Mid. Sec.}}$$

But whether the formula was theoretically correct, or not, it might be conceded as a standard of comparison, for recording the progress of naval architecture, on the same principle that the power of a steam-engine was calculated. Without using comparisons, by means of that formula the well-known list of screw vessels in H.M. Navy had been tabulated. This showed, that as the vessels with the highest velocities were all on the positive side of the speed deduced by the formula, it might be safely calculated, that the expenditure of power above the square would not negative the speed deduced, up to 18 miles per hour; this fact was adduced in proof that "the power only increased as the square of the velocity."

In proof of the assertion that the form was not necessary in calculations of velocity, Mr. Armstrong pointed out that the speeds of the 'Vulcan,' 'Minx' (diminished), 'Encounter,' 'Sharpshooter,' 'Himalaya,' and 'Ajax,' were deduced by the formula to within one-fifth of a mile; and the speeds of the 'Archer,' 'Arrogant,' 'Rattler,' 'Rifleman,' 'Niger' (diminished), 'Alma,' 'Candia,' 'Ava,' 'Aden,' 'Dauntless,' 'Phœnix,' 'Conflict,' and 'Amphion,' were deduced within one mile. These variations were believed to be entirely owing to the various degrees of efficiency of the propellers, as might be seen by the following Table:—

—	Ratio of Speeds.	Pitch to Diameter.	Revolutions.
Plumper	1·21	·62	100
Reynard	1·21	·91	108
Archer	1·13	·86	108
Arrogant	1·12	·96	55
Rattler	1·12	1·10	104
Rifleman	1·08	1·12	110
Niger	1·08	1·36	68
Alma	1·06	1·32	57

This Table was in exact accordance with experiments upon the 'Ajax,' 'Dauntless,' 'Minx,' 'Phœnix,' 'Plumper,' 'Rifleman,' (diminished), and 'Sharpshooter'; and therefore proved, that the form of the vessel was not the cause of the variation from the speed deduced by the formula.

The element "frictional resistance" was completely ignored by the power required, to attain nearly the same velocity, in the 'Himalaya' being 400 indicated H.P. less than the proportionate power to the midship section of the 'Fairy;' although the 'Himalaya' was three times as long, twice as broad, and had three times the draft of water, whilst the immersed surface was as 20 to 1; and by the fact, that the longest and largest vessels were all on the positive side of the speed deduced by the formula, and the smallest on the negative side.

In the cube theory, the combination of space with velocity was unphilosophical, and against the opinion of writers on Dynamics and Hydrodynamics. In the well-known tabulated list of screw steamers of her Majesty's Navy, the 'Minx' was the only example that favoured this theory. In a comparison of the 'Minx' (diminished), 'Teazer,' and 'Fairy,' the facts were in favour of the square theory; and from experiments on the same vessels, the 'Dauntless,' 'Desperate,' 'Termagant,' and 'Charlemagne,' the deduced power by the square theory was under the actual power in every case. In a comparison of the 'Himalaya,' 'Amphion,' 'Minx,' and 'Termagant,' the facts were decidedly in favour of the power increasing as the square of the velocity.

He attributed the increase of speed, by lengthening the bows of steam vessels, to the effect of that increased length decreasing the normal immersion of the after end of the vessel at high velocities, and not from any decreased resistance on the bow of the vessel. In corroboration of this, he stated, that the trials of the 'Flying Fish' showed no increase of velocity by the lengthening of her bows, at half, or three-quarter power, though with full power the speed was increased from $11\frac{1}{2}$ knots to $12\frac{1}{2}$ knots. As a further illustration, a vessel was assumed of the same displacement as the 'Himalaya,' but with rounder water-lines, drawing 18 inches less water, and having 70 square feet less midship section. He would then ask, whether the advantages of the sharp water-lines of the 'Himalaya' were equivalent to the rounder water-line of the assumed vessel, which had 160,000 tons less water to displace, in sailing one hour. The formula, when applied to the four experiments with the 'Desperate,' alluded to in the early part of the discussion, enabled the most effective and economical power to be ascertained. In the first experiment, with four boilers and four cylinders, the effective H.P. was 68 per cent. under the indicated H.P.; in the second, with three boilers and four cylinders, the effective H.P. was 45 per cent. under the indicated H.P.; in the third, with two boilers and four cylinders, the effective H.P. was only 17 per cent. under the indicated H.P.; and in the last, with one boiler and two cylinders, the indicated H.P. was 18 per cent. under the effective H.P. The inference he deduced from these facts was, that small boilers and large engines would be the most economical and effective, and they induced doubts as to the accuracy of the rule for calculating indicated H.P., which was further confirmed by the recorded results of the performances of the 'Retribution' and of the Dover Mail Packet 'Garland.' It had been said, that 169 indicated H.P. had propelled 440 square feet of midship section in the 'Desperate' at the rate of 7 miles per hour. This he believed to be impossible, for in the

	I.H.P.		Mid. Sec.			
Plumper ..	148	propelled	204	at the rate of	8·47	miles per hour.
Reynard ..	165	"	184	"	9.43	"
Archer ...	345	"	372	"	8·93	"
Ajax	846	"	807	"	8·16	"
Phœnix ...	382	"	347	"	8·11	"
Amphion .	592	"	546	"	7·71	"

In conclusion, Mr. Armstrong expressed the hope, that, whether the theory he advanced was true, or not, the discussion to which his Paper had given rise would tend to advance the science of naval architecture, and to bring Steam Transport Economy within the range of arithmetical calculation.

Mr. G. P. Bidder, V.P., observed, that the Paper had been, and with justice, severely criticised, for promulgating doctrines so decidedly at variance with the actual state of scientific knowledge; and as in the reply to the observations of the various speakers, the Author did not appear to perceive the errors into which he had fallen, the employment of other arguments with a gentleman who contended, that the power was not as the cube, whilst he admitted that the resistance was as the square, would be as useless as to attempt to hold a conversation with him in a language which he did not understand. Still the discussion would be useful in having elicited many facts which, if properly treated, would assist in throwing light upon the practical treatment of the question of the resistance to bodies passing through fluids.

Even Bossut and other eminent experimenters had neglected essential elements of resistance, and thus had permitted the existence of anomalies which had obscured the subject. For instance, whilst the effect of the angle of the bow had been carefully investigated, that of the angle of the stern, which was almost of as great importance, had been entirely neglected. The question of that important element, friction, also had not been duly considered, and although, when mentioned, it had been argued, that the friction of fluids in the interior periphery of a pipe differed from that of the exterior surface, such a proposition could not be admitted. It was incumbent on the Institution to prosecute this inquiry, to bring the subject within the province of scientific demonstration, and to reconcile the apparent anomalies with which it at present abounded.

The question also of the asserted increase of expenditure of fuel when working steam expansively in marine engines, must be thoroughly investigated, as though the effect of condensation might be considerable, in large engines working slowly, it was not sufficient to account for the augmentation of fuel expended in producing a less effect. If this explanation was correct, it showed that there was room for mechanical ingenuity to overcome the condensation, for in locomotive and in pumping engines there was undoubtedly economy, by working steam expansively.

With regard to the best form of vessel, that point could not be settled, without a series of experiments to determine each element of resistance separately, showing what was due to friction, what to the shape of the bow, and what to the shape of the stern. Mr. James Walker, (M. Inst. C. E.,) had many years ago made experiments on this subject, and had presented a Paper to the Royal Society, "On the Resistance of Fluids to Bodies passing through them."[1] These experiments were made with boats 20 feet and 28 feet in length, in the East India Docks, and by such application of power as could be correctly estimated and collated with the speed attained. All the results confirmed the accepted rule of the resistance being as the square, and the power as the cube of the velocity. This first series of experiments was not, however, so valuable as the second series, in which the angles of the vessels were altered definitely, and an account of which, it was hoped, would be given to the Institution.

There were many Members, from whom on all these questions, valuable Papers might be obtained. He hoped they would devote some of their time and knowledge for the benefit of the profession, and from the partial promises already received, there was reason to expect that such Papers would shortly be laid before the Institution.

March 17, 1857.

ROBERT STEPHENSON, M.P., President,
in the Chair.

The discussion upon the Paper, No. 961, "On High Speed Steam Navigation, &c.," by Mr. R. Armstrong, having been renewed, was continued to such a length as to preclude the reading of any other communication.

[1] *Vide* Phil. Trans. for 1828, pp. 15 to 22.