

### Discussion.

Sir J. W. Bazalgette. Sir J. W. BAZALGETTE, C.B., President, said, in proposing a vote of thanks to Mr. Barnaby for his interesting Paper, that it was just thirty years since the subject was discussed at the Institution.<sup>1</sup> The record of that discussion was very meagre, and perhaps it was well that it was so, for report stated that the discussion was exceedingly animated, and somewhat personal, and that the language used on that occasion was not altogether parliamentary. He was sure that on the present occasion the discussion would be animated; he was equally sure that it would be conducted without any personal feeling, in a perfectly "parliamentary" manner; and he could also promise that a true and complete record of the discussion would be given.

Mr. Barnaby. Mr. SYDNEY W. BARNABY asked permission to call attention to a diagram which had not been alluded to in the Paper, but was illustrated by a model on the table. It represented a small steam launch driven by what he had called a screw-turbine propeller (Plate 1). It had been already described at the Institution<sup>2</sup> and elsewhere, and he only alluded to it because it was really the outcome of the hydraulic-boat. It had been pointed out in the Paper that there were four features in the Ruthven form of pump which militated against its success as a propeller. In the first place, there was the difficulty of getting the water through the bottom of the boat and into the pump without checking the velocity it already had relative to the vessel. In the second place, there was the disadvantage of the extra weight of machinery involved by the necessity of carrying all the water acted upon. Thirdly and fourthly, there was the loss by friction and by bends in the passages. In working out the hydraulic-boat, it occurred to Mr. Thornycroft that if the turbine could be put outside the boat and under the bottom, the first two causes of loss would be avoided. It was also clear that if the water could be made to flow axially through the turbine instead of centrifugally, as in the Ruthven pump, no pipes would be needed, and there would be no loss by friction or by bends. This was what had really been done in the boat, illustrated

<sup>1</sup> Minutes of Proceedings, vol. xiii., p. 370.

<sup>2</sup> The Author refers to a Paper, "Light-draught Launch," by E. W. Cowan and J. Fawcus, Studs. Inst. C.E., read on the 15th of February at a Supplemental Meeting of the Students, and which will be printed in a subsequent volume of the Minutes of Proceedings.—SEC. INST. C.E.

by the diagram and model, to which he had referred. It might be said that it was not a turbine, but it would certainly be an abuse of language to call it a screw. He thought it might be fairly described as a screw-turbine propeller. Another point in its favour was that at least as light a draught (and in some cases a lighter) could be obtained as with an actual centrifugal pump inside the boat. In the second class torpedo-boat, if a screw-turbine propeller had been used, its diameter would have required to have been 21 inches only, and the draught could have been reduced from 2 feet 6 inches, which it was when fitted with the turbine, to 2 feet 2 inches. Therefore, the principal point which Lord Dufferin's Committee had mentioned as a reason for a further trial of the turbine propeller had been secured by a simpler method avoiding a great many of its disadvantages. The steering power also was very superior with the turbine underneath the bottom and near the end to what it was with the nozzles in the ordinary hydraulic-boat, the reason being that almost the full power of the engines was used in both cases; but in the steam-launch (Plate 1) it acted upon a leverage of half the length of the boat instead of a leverage of half the breadth, as in the case of the hydraulic boat. He thought it might therefore be taken that that was at any rate one solution of the problem of hydraulic propulsion.

Mr. M. W. RUTHVEN said that the Author had taken some trouble to show that great losses were sustained by the hydraulic mode of propulsion; the question, however, was not how much loss was due to the hydraulic method, but was the loss less or greater than by the screw? The safest way to get at that was by a comparison

"VIPER" CLASS.		"WATERWITCH."		"PHILOMEL" CLASS.		
9th May, 1866	274·8	Coefficient from	$v^3 \times M S$	14th Mar., 1868	302·0	
18th " "	297·2		I.H.P.	8th May "	316·0	
31st " "	328·0		1st Jan., 1867	342·7	20th Mar. "	299·0
5th Nov. "	317·7		17th " "	327·7	16th April "	274·0
4th June "	321·0		9th Aug. "	351·9	14th July "	329·0
5th " "	335·9		28th " "	328·7	20th Mar. "	279·0
2nd Aug., 1867	379·9		3rd Sept. "	303·3	20th May "	311·0
5th " "	437·6		12th Oct. "	357·8	19th Nov. "	294·0
11th Oct. "	424·8				12th May "	311·0
	9)3,116·9			6)2,012·1	27th Oct. "	272·0
	346·3		335·3		10)2,987·0	
	3·2		12·2		298·7	

of the results. It was for this purpose that the trials of the "Waterwitch," "Vixen," and "Viper" had been undertaken, though a comparison might also be made with the screw in other

Mr. Ruthven. ships. The Author had chosen to compare the "Waterwitch" only with the "Viper," and with a particular trial; but as the results of the trials of the "Viper" and "Vixen" varied nearly 60 per cent. the only approach to accuracy would be the mean of all the trials of both ships, compared with the mean of all the trials of the "Waterwitch." When that was done it would be found that the efficiency of the hydraulic propeller was within 3 per cent. of the screw propeller in the "Viper" and "Vixen"; but as the results of the trials of those vessels varied so much they did not form a satisfactory comparison. There was, however, a class of vessels called the "Philomel" class, with similar engine and boiler-power to that of the "Viper" and "Vixen," whose performance varied less. Now comparing the coefficients of this superior class of ships with the coefficients of the "Waterwitch," it would be found that the hydraulic-propeller in the "Waterwitch" was more than 12 per cent. better than the screw-propeller in the "Philomel" class. In Appendix II., Table 1, the coefficient of the hydraulic-propeller in the "Waterwitch" was put as 116·9, while that of the Swedish boat was 52·5, showing that the former was 122 per cent. better. The "Thornycroft" was stated to be 72, giving the hydraulic-propeller in the "Waterwitch" a superiority of 62 per cent. In Table II., however, this seemed reversed, for the total efficiency of the hydraulic-propeller in the "Waterwitch" was put as 0·180, in the Swedish at 0·214, and in the "Thornycroft" boat at 0·250. Now the use of the column of coefficients was to afford a comparison of efficiency, and this being so, that column in Table 2, showing a total efficiency, must keep the same relations as in Table 1. Mr. Froude, he believed, found that a good screw had a total efficiency of 0·40. Taking this to be correct, and seeing that the hydraulic-propeller in the "Waterwitch" was superior to the screw by 12 per cent., its total efficiency was thus proved to be 0·45; and unless the Author could show that the total efficiency of the screw-propeller was less than 0·18, he must be wrong in putting the total efficiency of the hydraulic-propeller in the "Waterwitch" at that figure.

Captain  
Heathorn.

Captain HEATHORN observed that five years ago Mr. Ruthven had given him copies of the Tables of the various trials to which he had referred, and he had himself given copies to many members of the Institution. He only hoped that every possible experiment would be tried to see if greater velocities could not be obtained. Mr. Thornycroft had invented something like a Giffard's injector, and had obtained a good result. The force was a flow of water instead of steam; surface friction was at work and produced the

required result. About eleven months before his recognition of surface friction as a means of propulsive effort, Captain Heathorn had tried experiments with many kinds of orifices, and found that the force of a stream of water, from a pipe under water, in the still water surrounding was, when once the flow began, not so much dependent on its sectional area, as on the surface contacts; and that if the area of contact was larger in proportion to the area of the section of the flow from a round pipe in one case and one of another form in the other, greater surfaces set up greater friction, greater speed resulted and less water was used. The Admiralty had put him in communication with the late Mr. Froude, who, in answer to a letter of the 20th of March, 1878, said that the proposition which he had laid down as the basis of his view was one with which Mr. Froude was familiar, and he went on to ask in what way Captain Heathorn proposed to apply it to the propulsion of ships. His answer was:—Contract the orifices or jets of H.M.S. "Waterwitch" to a certain form and do the same to the exit ends of the screw-channels of H.M.S. "Bruiser." Screw-channels, he believed, were invented by the late Mr. Griffith. Now that the Admiralty had a boat he hoped that they would persevere and find out what hydraulic power really was.

Admiral SELWYN considered the Paper an important contribution to the history of the subject. If any means could be adopted, even at the sacrifice of speed, to prevent ships and their crews going suddenly to the bottom by the impact of a torpedo or a ram, he was sure Englishmen would advocate spending a little more money for the extra power required to give the necessary velocity, and at the same time secure the other advantages. He doubted the accuracy of the statement in the Paper that the principles underlying the subject were perfectly understood; he thought that, otherwise, none of the experiments would have been made on the basis on which they had been carried out in the "Waterwitch" and the other similar vessels. The hydraulic arrangement seemed to present advantages which were apart from its use as a propeller; but wherever it was necessary to put a scoop into the bottom of a ship it would be found that there was a strong objection to it, because the scoop would be the first thing to encounter the ground on getting into shallow water. It would not, therefore, be liked for that purpose, however applicable it might be to a torpedo-boat. He had lost all faith in coefficients. He had lately seen a statement that the large and fast steamer, the "Phaeton," sister ship to the "Iris," had had about 600,000 lbs. weight of engine taken out, the engine-power being reduced from 7,000 HP. to 5,000,

Captain  
Heathorn.Admiral  
Selwyn.

Admiral Selwyn. and had been driven faster (more than 18 knots, with the same displacement and the same shape), and he confessed that coefficients would require a little more explanation before he could recognise their applicability to the subject. Engineers were apt to make a formula to fit certain cases, and to lay it down that those cases were the rule, and that all abnormal cases, as they were called, were the exception. It was strange that with the addition of 600,000 lbs. to the armour-plated deck, one vessel with 5,000 HP. went 18·3 knots an hour, while the other vessel with 7,000 HP. went 18 knots. An experiment mentioned to him some years ago by Mr. Gwynne, of Hammersmith, gave the following results: Diameter of disk,  $30\frac{1}{2}$  inches; orifice, 8 inches; revolutions, eight hundred per minute; indicated HP., 100; head attained, 90 feet, with a discharge of 800 gallons per minute; thus there was a pressure of 45 lbs. per square inch. The effective thrust was 2 tons. Of course to the 45 lbs. per square inch would have to be added the 800 gallons per minute discharged at the top of the 90 feet. There was an important anomaly in all the records of the "Waterwitch." Engineers would readily admit that there was no departing from the law of action and reaction being equal and contrary, and when any one told him that a pump, whose peripheral velocity was 29·3 feet per second, gave a velocity of discharge of 29 feet per second, he thought some other explanation should be sought than that which was found in the pump itself. Unless the velocity of the feed was there utilized, he did not see how such an effect could be produced. If it were produced, the pump would be undoubtedly an absolutely efficient machine. It might be expected that as the disk-pumps were enlarged there would be an increase of efficiency. All experience pointed to that. While in the smaller pumps the velocity of the issuing water was not more than about 50 per cent. of the peripheral velocity, in the larger pumps 60 and even 70 per cent. had been obtained. Distrusting formulas, he took the percentage by calculating the revolutions into the circumference, finding the peripheral velocity of the disk from that, and getting the discharge as a percentage of that peripheral velocity. When 37·2 feet per second had been obtained as the velocity of discharge, and the velocity of feed was 20 feet per second, he presumed that only 17·2 feet per second had been communicated by the engine to the water. If that was the case, might not the anomaly in the "Waterwitch" be attributed to the velocity of feed from those inlets? A set of mouths, immediately under the pump scooped downwards, as was the case in the later trials of the "Waterwitch," would give a certain velocity of feed into the pump, and

that might be added to the peripheral velocity, so explaining what otherwise seemed to be utterly inexplicable? He had found that various sources were accessible for an account of the revolutions of the "Waterwitch" engines, and while he had found them sometimes stated at forty-two, they occasionally descended to forty per minute. Engineers, he thought, would be thoroughly aware of the vice of taking revolutions either through another observer or at a different time from that at which the indicator diagrams were recorded. Any possible HP. might be indicated in such a way, and give rise to a very false basis of coefficients. It appeared that in the "Thornycroft" propeller a velocity of 56 feet per second had been obtained—he presumed a peripheral velocity—and the velocity of discharge was 37·25 feet. That velocity was much more important than quantity of discharge. The volume did not matter in the least in regard to the velocity obtained. The whole power of the engines might be thrown away in lifting a mass of water, but if the necessary velocity to produce the speed sought was not communicated to the water, most engineers would say it was vain to seek it at all. It would be interesting to try an experiment first by towing the boat with her inlet so arranged and the scoop so arranged at the velocity which she had obtained with the engines at rest. It would then be seen how much the velocity of the inlet-water was diminished by passing through the pump at rest. Next, to tow the boat with such revolutions of her engines as would give a peripheral velocity equal to the speed of the boat. And, lastly, at the calculated velocity of feed. Those three experiments would bring out exactly the efficiency produced by the feed as distinguished from that produced by the pump. Now, supposing that the revolutions of the screw-engines had not been changed, but that the diameter of the nozzles had been diminished from 9 inches to 6 inches, and the disk increased to 2 feet 9 inches, what might be expected? He thought it would be found, taking the basis obtained by the Author's experiments of 56 feet peripheral velocity, and 37 feet velocity of discharge, that 60 feet per second velocity of discharge should be obtained with 91 feet per second velocity of periphery. That would correspond, provided the water thrown was sufficient, to bring out a proportionate pressure. He was not aware whether the pressure per square foot of midship-section to drive the boat 17·3 knots per hour had been calculated, but, whatever it was, it could no doubt be made up. The velocity of 91 feet per second peripheral, and 60 feet discharge, would give about 17·7 knots per hour. He was sure that would be impracticable with a less speed of discharge.

Admiral  
Selwyn.

Admiral Selwyn. water. If the number of revolutions per minute were diminished, the speed of the boat could be arranged without any possibility of change. Every experiment he had made brought out the fact that the speed of revolutions was indissolubly connected with the speed of the boat. If, therefore, the principles underlying the subject had been thoroughly understood, the first question asked would have been, "What speed is it wished to get from the boat?" That would govern the revolutions or the revolutions multiplied into the periphery of the disk. The disk might be made a little larger and then the revolutions might be diminished, or the revolutions might be increased and the disk diminished. But, as Mr. Gwynne's experiments showed eight hundred revolutions producing a thoroughly good effect, with one 8-inch issue, there need be no fear. He had himself driven a small 1-foot pump at one thousand revolutions, and on the basis to which he had referred he had obtained exactly the calculated speed of the boat. The pressure per square foot midship-section was, as nearly as he could make out at the velocity and size of nozzle stated, 120 lbs. He presumed that that would be scarcely sufficient for a speed of 17.7 knots per hour, but it could be easily increased. In regard to the possibility of pumping the ship out with the full power of the engines, if any issue was opened from a drowned compartment (where the water must be on a higher level) to the turbine, he failed to see why the turbine should chose between the bilge-water and the other water. He thought it would certainly take a larger quantity from the easier path of the inlet, but that it would take a portion from the bilge that would probably be sufficient to keep the boat from sinking, or result in so far prolonging its floating above water as to save human life. That result would be sufficient to justify any trials. It could scarcely be supposed that in the event of another war there would not be a lesson to learn as to the effects of rams and torpedoes. Mr. Thornycroft had done so much and so well in providing the means of destroying the British and other navies that it was only fair to ask him to throw a little of his energy, skill, and genius into the question of how to save human life and the expenditure of ships.

Sir Edward Reed. Sir EDWARD J. REED, K.C.B., M.P., thought the Paper was a very important contribution to the knowledge of the subject of hydraulic propulsion. The last bearing on the subject was the comparison referred to by Mr. Ruthven and other speakers between the "Viper" and the "Waterwitch." Admiral Selwyn had expressed his distrust of coefficients and of formulas, and Sir Edward Reed supposed that all engineers distrusted them when they only took

account of a fractional part of the circumstances they wished to consider. There were very peculiar circumstances in the case of the "Viper" and "Waterwitch" trials. In the first place he might say, as the designer of the boat, that the "Viper" was about the very worst screw-propelled vessel, that had ever been built, and that for a very good and sufficient reason. She had to be designed to pass through certain locks; her length and her breadth therefore were arbitrarily determined, and her depth also had been similarly determined. Having thus a parallelopipedon which was to embrace the "Viper," there had to be carried by it certain armour and guns, and particularly as much as possible of the armour. The speed was of very minor importance, and it had been deliberately subordinated to the armour-carrying and gun-carrying power. It would therefore be seen that the "Viper" and "Vixen" were rectangular boxes, slightly improved, with small regard to propulsive advantages, and he thought they were about as bad vessels as could have been designed. Admiral Sir George Elliot, impressed, like Admiral Selwyn and many others, with the great advantages of hydraulic propulsion to Her Majesty's ships at sea, put a strong pressure upon the Admiralty to get the hydraulic-propeller tried, and holding at the time a high official position, and being an officer of great experience at sea, and of much deserved influence, he succeeded in inducing the authorities to try a hydraulic-propeller in a vessel of the class referred to, or a vessel of about the same dimensions. There were reasons, however, tending to show (the figures given by the Author did not fully demonstrate it, but he had no doubt Mr. Ruthven would readily concur) that the form of the "Waterwitch" was superior to that of the "Viper" and the "Vixen," because when she was designed some limitations imposed upon the other vessels had been removed. A considerable improvement in form was realized, and the trials were made, and, as far as his memory went, the figures given by the Author fairly represented the state of the case. Taking Mr. Ruthven's figures, it would be seen that the bad screw-propelled vessel was a little better than the hydraulic-propelled vessel, even at the low speed of  $9\frac{1}{2}$  knots per hour. The trial certainly made a good show for the hydraulic-propeller by comparison with a bad screw-vessel—a better result than had been expected by many persons; but what would happen when higher speeds were attempted? The Author's Paper contained a case in point. The Government had sought to give effect to the recommendation of some of the members of Lord Dufferin's Committee, or of the Committee itself. They had gone to a gentleman who had dis-

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tinguished himself in the design and production of vessels of the torpedo class, Mr. Thornycroft, to whose genius the introduction of these light and extremely fast vessels was due, and they had asked him to do the best he could in establishing a comparison between the hydraulic and the screw-propeller designed for high speed. The result was that with a given HP. in two vessels made as nearly alike as the circumstances would admit, the hydraulic vessel steamed at a little over  $12\frac{1}{2}$  knots per hour, and the screw-propelled vessel at a little over  $17\frac{1}{4}$  knots. Admiral Selwyn had referred to the statement in the Paper that the jet as a propeller might be taken as a little better than a screw, but he had forgotten to complete the sentence: "But the loss in the pump is a dead loss, and represents about half of the power." He did not know what the experience of others might be, but he could say for himself that, if he had to devise a fast or any other steam-vessel, to lose half the power in order to secure an efficient propeller would be a very sad imposition to have placed upon him. He was unable, as he always had been, to anticipate any satisfactory result from the hydraulic system of propulsion as applied by means of internal pumps in the ship. He sympathised with the objects that Admiral Selwyn and other naval officers had in view, and he should be delighted to see growing out of the discussion some relief from the loss which the system always involved when so applied. He confessed that his sympathies went very strongly in favour of the apparatus described by the Author after the reading of his Paper, viz., the application outside the vessel of an arrangement by which the good effects of hydraulic propulsion might be obtained in a large degree without its serious disadvantages. With regard to Mr. Ruthven's reference to the mode of conducting the trials, he thought he ought in fairness to say that everything had been done at the time that could in reason be done to satisfy Admiral Elliot, who was known to be more or less in communication with Mr. Ruthven. He had also to state that he believed that the consideration of the subject had been brought to an end because the discussions between Admiral Elliot and the Admiralty had passed away from the efficiency of the jet system to questions about the indications of power in the engines of the "Waterwitch," and other collateral matters, so that the essential part of the subject had in some way fallen out of discussion. He was sure it would be the desire of the Council and of the members that every possible opportunity should be given to gentlemen capable of discussing the subject to direct the minds of the members to some methods, if methods there were, by which to get rid of the enormous loss

sustained within a ship by the application of the hydraulic system for its propulsion. Sir Edward  
Reed.

Admiral Sir GEORGE ELLIOT, K.C.B., said he would not venture to enter the domain of science; all that he knew of hydraulics he had learned from personal observation of the practical results which had been hitherto obtained. He was greatly pleased when he heard that the subject was to be discussed by the Institution, on account of the great advantages to navigation which would accrue even from a partial application of hydraulic propulsion to ships. He did not think that hydraulic propulsion had ever yet had fair play; it had never yet been tried on its merits. Certain conditions had been attached to the experiments which he thought had marred the best efforts of engineers. The "Nautilus" had not been designed with the sole view of developing hydraulic motive power in a ship; the owner had a commercial object in view. He looked to a commercial enterprise, inasmuch as the vessel was designed to run up the Thames to Richmond; consequently, with a light draught and having to carry a large number of passengers, she had full lines; still the speed realized by that vessel was  $9\frac{1}{2}$  knots per hour. He thought the Author had made a mistake when he said 8.32 knots. She was raced on the river against a vessel called the "Volunteer" down to Gravesend, and she distanced her. The "Volunteer" was a vessel of 24 HP., whilst the "Nautilus" was 20 HP. She afterwards raced constantly with the "Citizen" boats, and to his knowledge she beat them. Then a challenge was held out to any paddle-boat on the river, but it was not accepted although an offer was made to pay the expenses. No one could say that the "Waterwitch" was a good specimen of naval architecture in which to try an experiment. The constructors had a very difficult task in making armour-clad gun-boats, and the designer looked upon them as very bad specimens of naval architecture. However, the "Waterwitch" in her first trial at the Maplin Sands realized a speed of 10 knots per hour. At that time in a contest between the "Viper" and the "Vixen," her two sister vessels, the latter was the slower of the two, therefore the trials afterwards took place between the "Viper" and the "Waterwitch"; the former vessel at the Maplin Sands obtained the same speed as the "Waterwitch." They were afterwards taken to Portsmouth where the trials went on. The builder's trim of the "Viper" was 1 foot at the stern, at which she was run at the Maplin Sands; but at Portsmouth she was brought down to 2 feet at the stern, and the bow lines were thus lengthened, whilst the "Waterwitch" was compelled to remain

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on an even keel. The trials gave the advantage to the "Viper" of  $\frac{1}{4}$  of a knot speed. In the "Waterwitch" the water came in to the turbine from forward through a canal, with holes perforated in the bottom. The turbine was raised unnecessarily high, and the discharge pipes were raised still higher, in order to test the differences between discharging the water above water when she was at her light trim, and in the water when she came down to her load draught. He considered both those features to have been adverse to the success of the hydraulic method of propulsion. Those vessels went to sea, but they were found to roll so heavily as to be unseaworthy, and they were afterwards laid up and lightened and taken out to Bermuda; the "Waterwitch" was laid up in ordinary. Some years afterwards, when he was appointed Dockyard Superintendent at Portsmouth, the Admiralty allowed him to have the "Waterwitch" to make some experiments. He had an idea that leading the water in through the bottom of the vessel in a canal, by which a large quantity of water was carried about, necessitating increased displacement, was a mistake, and he was determined to ascertain how far it would be advantageous to bring the water in from forward or from directly underneath the turbine. The trials were carried out very carefully by the dockyard officers. He merely asked them to close the canal and to open underneath the turbine a hole and to insert a tube, and let the water enter directly underneath the turbine. The vessel was taken into dock and cleaned, put to a certain trim, run at the mile, and her speed ascertained. She was then docked. The alteration was made; she was again cleaned, put to the same trim, taken to the mile, and the result was  $\frac{1}{2}$  knot additional speed per hour. He then thought that the turbine to be at its best should be brought as low in the vessel as possible, the water admitted from underneath, and the discharge-pipes horizontal. In the "Waterwitch" they were raised, as he had said, which was certainly an objection. He still believed that, in order to try the hydraulic-propeller at its best and give it fair play, a vessel should be designed for the purpose, a double-ended vessel with a rudder at both ends, on an even keel, and the hydraulic-propeller as low as possible, in point of fact to work in the water. He had reasons for believing that bringing the water up to the turbine from directly underneath was an advantage. His idea was that directly the turbine was turned a hole could not be made in the water, and a column of water at a certain speed was immediately set in motion, which was greater than the speed at which the ship was going through the water; consequently the greater velocity overcame the lesser velocity due to the momentum of the vessel; in

fact there was no loss of power. If the turbine was very low down the bottom of the turbine might almost be brought to the sea itself. Having a rudder at both ends the vessel would go equally fast both ways; in fact, in the trials in the "Waterwitch," although the water was brought in forward it did not make much difference in her speed one way or the other. That told very much against the attempts that had been made to draw the water in from forward by pipes from the bows. He could understand the object in view; and theoretically he could see that it appeared to be a wise one; but as far as that trial in the "Waterwitch" went, it proved not to be so. Then he made an experiment to ascertain what the size of the discharge pipes should be. The Admiralty were again good enough to carry out his experiment, by putting a flap on a hinge inside the nozzle, which could be pushed out, so as to close the aperture or leave it wide open. The speed of the water at the discharge was measured, and it was found when the nozzle was half closed the water was going out at double the speed; therefore the same quantity of water was discharged as when it was wide open—the speed of the vessel in both instances being the same. That showed that the nozzles of the "Waterwitch" were unnecessarily large, because he believed that the best result was obtained when the pipes were completely filled, but trials were made at different revolutions of the turbine, and it did not appear to signify much. He did not agree that the turbine would not work unless it was full. The Author had described all the advantages (and they were very great) of the turbine as a propeller for ocean purposes, but he had not specially named one benefit which he thought the most important. If a vessel could be stopped, without any reference to the engine-room, in her own length, and if two vessels meeting could do the same, he believed there would be very few collisions. Another feature was the advantage that it afforded in foul weather. The accidents in screw-boats that then occurred were generally caused from the racing of the screw; but the greatest amount of motion a ship could be put into would not in the slightest degree bring a greater strain upon the engines of the turbine. After a considerable time, the subject was again mooted at the Admiralty, and then came the trial of the Thornycroft torpedo-boat, respecting which he was greatly pleased to think that the experimental trial had been placed in the hands of that firm, who, he had no doubt, had taken pains to make it a success. But as a competitive trial it was inadequate. The Author had stated that the object of the Admiralty was to have vessels of very light draught of water in

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waters so shallow as scarcely to afford sufficient immersion even for twin screws. In a fair trial both vessels should have been put to the same test, which was the draught of water. But in the case of the turbine the draught of water was 2 feet 6 inches, while that of her opponent was 3 feet 8½ inches; and in the screw-boat the shaft was on the keel, and nearly half the blades revolved below the keel, giving a large diameter to the screw, added to the extra draught of water. In this competitive trial the screw torpedo-boat would require a depth of 6 feet of water to work the screw, whilst the turbine boat would only need a depth of 2 feet 6 inches to move about in. That was unfair to the turbine which had not those advantages. The two trial vessels should have had the same draught of water, similar displacement, and similar power. If the draught had been 2 feet 6 inches, and the screw had been limited to that diameter, he thought that a very different result would have been obtained. He should be much pleased if Messrs. Thornycroft and Co. would build a boat exactly as he had described, with her turbine low down, with the entrance of water from below, with the discharge-pipes horizontal ejecting the water under water, and with the valve like that in the "Waterwitch," and then see what speed they could get out of the screw with a diameter of 2 feet 6 inches with the same power. Then again one boat was brought by the stern, and the other was on an even keel; but both boats ought to be confined to a given draught of water. He would give the turbine boat rather a full body, so as to lower the turbine and get as much benefit from the full diameter as possible. In the vessel in question, the diameter of the turbine was small, and the discharge-pipes were long. It appeared to him that the importance of centrifugal force had been lost sight of, and this he had always understood to be an advantage in the turbine, by not having a large diameter so as to discharge the water at a rapid rate through the pipe, and reduce the revolutions of the turbine. Another advantage of admitting the water from below was that it was not necessary to carry the same volume of water in the canal as had to be carried in the "Waterwitch"; it was only necessary to carry the water which the turbine itself contained. When he spoke of the partial success of the turbine, he referred to its use in sea-going vessels as an auxiliary power. With power sufficient to give a speed of 8 knots per hour, to get across calms and in and out of harbour, an enormous advantage would be gained. Unfortunately the hydraulic-propeller had not had many friends. Whenever he had approached the shipbuilder on the subject, he had been told that it would cost

a great deal of money being a novelty, and that at once had put an end to the idea. On one occasion at Portsmouth a lady, in delicate health and unable to stand the vibration of a screw, was towed about in her yacht by a tug. He endeavoured to get a turbine put into a vessel that the lady was having built, but it was stated that it would have added £6,000 to the cost. He should be glad to see hydraulic propulsion tried still further, and felt sure that better results would be obtained if it were tried fairly on its merits.

Admiral RYDER observed that he had paid some attention to the subject from the commencement. He had taken a run in the "Nautilus," and two or three trips in the "Waterwitch." A few days ago he went out from Portsmouth to Spithead in Torpedo Boat No. 87, which was irreverently called "The Squirt." It was a moderately fine day. The vessel was a remarkably good shape forward for riding over the sea, but the two tubes for ejecting the torpedoes were unfortunately conduits for seas that came over forward, and which dashed through the tubes against any one on deck with great force. The tubes should have wooden plugs. When going at 12 knots an hour, he said to the lieutenant in charge, "I think you may ease her," and his reply was, "We must either stop or go full speed." If that was the fact, it was certainly an unfortunate position for one of Her Majesty's vessels to be in. The sensation was peculiar when the boat stopped short. She stopped very dead, which of course was what was wanted in the case of a torpedo-boat. But he could not make out why the ejection orifices were above water. The noise was like soda-water bottles going off continuously. The tremendous noise would, he should think, on a calm day inform an enemy 10 miles off of the approach of the boat. He could not believe that it was in the "specification" that the orifices should be above water. Perhaps there was some good reason for it, but from his point of view as a sailor this feature was a most objectionable one. The nuisance of the noise was intolerable, and he thought that any Admiral would send the boat home by the first ship; he hoped that in future designs the orifices would be under water. One of the great advantages of that class of torpedo-boat was the freedom from danger of fouling. Seafaring men and engineers could easily picture what would happen on going into a harbour protected by nets with the ordinary form of torpedo-boat having one or two enormous screws; these would be sure to come in contact with any obstruction of that kind. It was all very well for the open sea, but he did not believe that such a boat would get inside an enemy's

Sir George  
Elliot.

Admiral  
Ryder.

Admiral Ryder. harbour at all. The turbine principle was a capital one for that purpose, because there could be no fouling by nets or anything of the kind. Another valuable feature was the power of changing the course to the opposite direction suddenly. A torpedo-boat fitted with any system of screws could work end on, bow foremost, but could do nothing against the enemy stern foremost; whereas if the turbine principle were further developed, and applied to larger vessels, an enormous advantage would be gained; indeed, the utility of the ship might be almost doubled. After having gone through the enemy's fleet, and struck or missed a ship, a turbine vessel might at once reverse her engines and retrace her course, without exposing her side, as the screw-vessel would do when turning. Of course the great question was whether the numerous advantages named by the Author, not omitting that invaluable feature that the turbine-propeller could not be "pitched" out of the water, as the screw frequently was, were worth paying for, and to what amount. They might be paid for in reduced speed. Would it be worth while sacrificing 2 knots, or how many knots, an hour to obtain the advantages that had been described? A committee of naval officers would soon come to a determination on that point. If the authorities would not pay in speed, would they pay in money? It might be necessary to get a larger or a narrower boat, or to give up some other feature to which importance was attached. He agreed with Admiral Sir George Elliot and Admiral Selwyn that the turbine question was not yet settled. The system had been tried by different nations. Swedish naval officers attached great importance to it. When he was commander-in-chief at Portsmouth, whenever a Swedish man-of-war came in, he always asked the officers how the turbine system was getting on. Their reply was that it was so unpopular with the Construction Department that they were not at all sanguine that it would be favourably received. At length, however, a turbine vessel was tried, and on enquiring the result, the reply he received was, "They have managed to make it fail." A round sum in thousands of pounds should be offered for the best design of a turbine torpedo-boat, capable of a speed of 20 knots per hour, and with orifices under water.

Mr. Wright. Mr. J. WRIGHT, C.B., Engineer-in-Chief of the Navy, said that the subject had been so fully and fairly discussed in the Paper that he had very few remarks to make; but there was one point which had not been much referred to during the discussion, namely, the great advantage supposed to accrue to a vessel with a hydraulic-propeller in turning power. It had been tried in the case of the

“Waterwitch” and the “Viper,” and the advantage was certainly very much in favour of the “Viper.” It took the “Waterwitch” twice the time to turn a circle that the “Viper” took when one screw was worked ahead and the other astern. Another point of importance was the great advantage claimed for the hydraulic-propeller in clearing the ship of water in the event of her getting a hole in the bottom. The Author had referred to the practical difficulties which would have to be overcome in opening and closing large sluice-valves in order to carry out such an arrangement. From some of the preceding remarks, it might be supposed that the naval architects of the present day had given no attention to the important matter of saving life on board ship, in the event of a large hole being made in the bottom; but any one acquainted with modern ships of war would know that an extensive subdivision was carried out for that very purpose, so that if two, or even more, compartments were penetrated, a large power of flotation would still be left. If a hydraulic-propeller were fitted for ejecting water from the ship, it was just possible that if a hole were made by a torpedo in the compartment containing the propeller, the propeller would be disabled. If, again, a hole were made in another part of the ship, there would be a difficulty in getting the water under the propeller in anything like sufficient quantity to keep it charged. No doubt Admiral Sir George Elliot had made an improvement by closing up the holes in the “Waterwitch’s” channel forward, and opening a direct hole under the bottom. The coefficients of the performances (though one gentleman had declared his disbelief in coefficients) showed an improvement of something like 15 per cent. But with regard to other experiments made by Admiral Sir George Elliot, in curtailing the size of the discharge-nozzle, there was a decided falling off to the extent of over 7 per cent. There was another point with reference to the “Viper,” namely, that the screw-propeller, acted on ten times the amount of water that passed through the turbine. If any one would examine the theory of the subject, he would find that that was a very important matter in regard to the superior efficiency of the screw. Comparing the two torpedo-boats in the same manner, it would be found that the screw-boat acted upon five times the amount of water that the turbine had acted upon.

Mr. R. SENNETT observed that there could be no doubt that the torpedo-boat referred to was the outcome of engineering skill of the highest order, and of workmanship of the greatest perfection; and with what result? Practically this, that the speed attained

Mr. Wright.

Mr. Sennett.

Mr. Sennett. was no greater than could be obtained from a screw-boat of equal size working at about one-half the power. The causes of this defective performance were not difficult to determine, and were, in the main, inherent to the system. All propellers worked on the same principle, namely, the projection of a volume of water sternward, and the thrust of the propeller was measured by the momentum or change of momentum produced. The more directly sternward the water was projected the greater the efficiency, all transverse motion representing wasted energy. In the jet every particle was sent directly astern, and therefore, theoretically, neglecting friction, the jet was the most perfect of propellers. It was from practical difficulties that the pump failed as a propeller; and though engineers were loth to apply the word impossible, yet in this case many of the obstacles were apparently insurmountable, and in his opinion the pump was never likely to become a general and efficient propelling agent, though it might perhaps be useful in some special cases. This arose mainly, as had just been pointed out, from the large volume of water that had to be dealt with, and the large orifices that would be necessary in the ship's sides to obtain high efficiency of propulsion. The thrust of a propeller depended on the mass of water operated on, and consequently, other things being equal, the propeller that could operate on the greatest volume of water would be the most efficient. Perhaps the custom of speaking of this propeller as a jet-propeller might unintentionally convey the idea that it was different in principle from other propellers. This, however, was not so. The jet was no more the propeller in this case than was the race of the screw or paddle in ordinary ships. As a matter of fact, the pump was the propeller, for it was the agent that drove the water astern from the momentum of which propulsion resulted, just as the screw and the paddle were the machines for driving the water astern in ordinary cases. In the hydraulic-boat the propeller was placed inside; in the paddle and screw outside; the action in each case was the same, only the machine was different. Until pumps were fitted that could cope with as large volumes of water as the feathering-wheel, and at about the same speed, the hydraulic propeller would not be able to approach in practical efficiency either the screw or the paddle, irrespective of the greater losses that might be expected from the friction of the water in the passages. If the pump were made to satisfy these conditions the large orifices necessary would, in most cases, be inadmissible, whether above or below the water. Then also the question would arise, would it be desirable to place such a propeller in what

would practically be a trunk in the ship, occupying valuable space and involving the carrying of a considerable weight of water? Or would it not be preferable to place the propeller outside the ship, and make proper provision for a sufficient flow of water to it, without compelling the water to pass through and be carried by the ship? He had little doubt as to the answer that would be given by the vast majority of naval architects to this practical question. Mr. Sennett.

Mr. JOHN I. THORNYCROFT said that Captain Heathorn appeared to convey the idea that the friction of the external surface of the stream of issuing water had some advantageous influence in propelling a vessel, and he applied his remark to an experiment which he had made where an induced current of water was used to augment the propelling effect. He desired to go into some detail in order to explain the matter. A stream of water issuing from a vessel had a re-action depending simply on the weight discharged in a given time and the velocity of discharge; the effect was unaltered by the form of aperture at which the stream found exit. The stream being submerged made no change in the re-action of the initial stream, but it then was in a position to induce other streams which might act favourably or unfavourably in propelling—favourably when the pressure was reduced on a surface attached to the vessel which had a motion towards the loss of pressure, and the contrary if motion of the surface was in the opposite direction. One way of taking advantage of this principle was to surround the stream of water from an ordinary screw-propeller by a conical tube of such dimensions as to allow an annular stream to pass through it around the stream from the propeller. When this was so placed that the initial stream entered at the larger end of the portion of a cone, and by the friction of its external surface and intermingling with the surrounding water induced a stream through the coned tube, the pressure within this tube would be reduced and the forward component of the difference of internal and external pressure would be available for propulsion. But in order to estimate the useful effect, the friction of the surface of the coned tube must be taken from the forward component of the pressure already alluded to. Experimentally he found that if a vessel was fitted to utilize the currents so generated, although it would be able to exert a greater pull at a fixed object in still water this advantage would diminish as speed was attained, and it appeared that at a useful velocity of vessel the apparatus was a failure: but he thought the result obtained by Captain Heathorn must be explained in another way. He thought that Captain Heathorn had Mr. Thornycroft.

Mr. Thornycroft.

fallen into an error. He had described an experiment that he had made, and he understood him to say that from water issuing from a pipe he got a certain re-action, and by contracting the pipe so that less water came out he got a greater re-action. He thought it was evident that in the first case most of the work was done by the friction of the water in the pipe, and in the second case, although less water came out, it came out at a higher velocity, and so the result was obtained. Captain Heathorn's allusion, therefore, to the apparatus to which he had referred was not correct. Admiral Selwyn had alluded to a pump, which he said gave a certain duty, and he spoke of 100 HP. working a disk  $30\frac{1}{2}$  inches in diameter at eight hundred revolutions and raising 800 gallons a minute 90 feet. On looking at it Mr. Thornycroft expected to find a good result; but he had computed the efficiency to be only a little above 0.22. Admiral Selwyn further stated that there was a pressure of 45 lbs. per square inch, and that to that would have to be added 800 gallons per minute discharged on the top of the 90 feet. At first he was puzzled to know how that was to be added; but in taking into consideration the 8-inch pipe, which he described, he found that the water flowed through it at 6 feet per second, and what was really to be added to the 90 feet was therefore the head due to the velocity of 6 feet per second. On working that out he found that it came to about  $\frac{1}{2}$ -foot, and instead of lifting water 90 feet it was lifted  $90\frac{1}{2}$  feet. He did not know what the percentage was, but it was perhaps 22 or  $22\frac{1}{2}$ ; so that he was afraid that the pump mentioned by Admiral Selwyn did not compare favourably with his own. The discharge of the pump described by Admiral Selwyn was immensely less than the discharge from the pump of the hydraulic-boat, although the disk was the same size and the revolutions were nearly double. Admiral Selwyn had stated that in what he considered a perfect pump the water discharged had the same velocity as the periphery of the disk. That, he thought, was entirely illusory. In one case it might be nearly correct. If only a little water was allowed to flow through a large pump, so that the water was a long while in the disk, no matter of what shape the vanes were, the water in the disk attained practically the same velocity as the disk of the pump. He believed that when the flow was limited in that way all pumps gave about the same lift with the same speed. He had exhibited some diagrams in which the form of the blade had been considered. In the case of the hydraulic-boat that he had constructed, the discharge was large and the motion of the water through the disk was rapid; therefore, the effect of the blade form

was very manifest. In considering the effect of the shape of the Mr. Thornycroft. blade it was necessary to take into account the speed of the water from the centre to the edge of the disk. The result of the diagram was to show that, taking into account the form of the blade, the water flowed through the pump at just the velocity it ought to do. In the pump of the "Waterwitch," the sectional area of the channel was so large that the water made a turn and half another turn round the disk before leaving the pump-disk. The result came out that the velocity of the periphery was 29.6 feet per second, and the velocity as measured in an equal interval of time was 29 feet. It was exactly 29 in the Author's figures, which was perhaps too close a coincidence. In the case of the Swedish pump the result was not so coincident, the velocity being only 21 out of 23 feet per second. Admiral Selwyn, therefore, was incorrect in saying that a perfect pump was a pump in which the velocity of discharge equalled the velocity of the periphery. He might say further, that if instead of using the radial blade a scoop blade throwing the water forwards were used, under favourable conditions it would possibly make the discharge equal to double the velocity of the periphery, it being assumed that friction might be neglected. It would, therefore, be more than a perfect pump, because by Admiral Selwyn's estimate it would be a pump with an efficiency of 2. Captain Heathorn had stated that the channel screw was invented by the late Mr. Robert Griffiths. He believed that Mr. Griffiths did put a screw in a tube; but the idea of putting a screw in a tube with vanes to alter the direction of the water from the spiral to a direct run out was due to Mr. Arthur Rigg. He put curved vanes behind the screw, and so got some advantage; but he did not contract the channel as the velocity was increased, and in that way secure the full benefit from the arrangement. Admiral Selwyn had calculated the re-action of Mr. Gwynne's pump at about 2 tons. That was surely too high, because he found that a cylindrical column of water 90 feet high and 8 inches in diameter would weigh about 1 ton. In a jet-propeller double that, or about 2 tons, would be obtained if it issued at its own speed, but in the case in question it only issued at 6 feet per second. If the water would issue as slowly as that, and give all the re-action, it would be correct; but, as it would escape at a much greater speed than that, the water would not supply the nozzle. Admiral Sir George Elliot had referred to the "Waterwitch," and to the way in which the water was led to the propeller. He believed his statement was correct, that the arrangement for leading the water to the pump through a canal was inefficient.

Mr. Thornycroft. Where the water entered through parallel plates the velocity was not converted into pressure. In order to convert the speed of a stream into pressure it was necessary that it should enter the small end of a tapering canal. He was not surprised that the channel was found from its surface friction to retard the effect of the propeller. Admiral Sir George Elliot had stated that the discharge seemed to be independent of the size of the nozzle. But Mr. Thornycroft thought there must have been some inaccuracy in the measurement of the speed with which the water had been ejected. With reference to the question of stopping a ship in its own length, it should be remembered that was quite a different thing from stopping a boat in one length. It appeared to be intended to put very large powers in ships; but in the case of a merchant steamer steaming at 14 knots per hour it was admitted that in starting the vessel the propeller was acting efficiently. A large steamer that would go at 14 knots per hour took a long time to attain full velocity, and if the propeller acted efficiently he supposed it would take the same time to stop. Admiral Sir George Elliot considered that the trial to which reference had been made had not been a fair one, and that the boats could not be fairly compared. Nevertheless, the best had been done, and even looking at it at the present time, after seeing where a slight failure might have happened, he did not know that if the work had to be done again it could be done much better. He thought it must be admitted that the discharge being above water-mark was a very great inconvenience. Whether the water could be discharged without loss below water-mark he was not sure. It would involve carrying a great deal more water within the boat, and it would have to be taken obliquely out of the skin. If the present nozzles were projected into the water so that they were forced through the sea he was sure the loss of speed would be very great.

Mr. Rennie. Mr. G. B. RENNIE remarked that the extraordinary speed of  $17\frac{1}{2}$  knots per hour in the case of the last torpedo-boat had been arrived at after a great many trials; the speed of the first boats of the same size had been only about 14 knots, so that the comparison was hardly a fair one. In trying various forms of pumps several years ago, in experiments for some large pumping machinery,<sup>1</sup> he found that the efficiency of the "Swedish" pump far exceeded that of the "Thornycroft," which was very much like the pump described by Professor Rankine.<sup>2</sup> The total efficiency of the pump and engine

<sup>1</sup> Transactions of the Institution of Naval Architects, vol. xxiv., 1883, p. 126.

<sup>2</sup> "The Steam-Engine," p. 190.

varied from 0.30 to 0.50. He did not think it got so low Mr. Rennie. as 0.25, as in the cases alluded to in the Paper. The way in which the calculation was made was this: the dock was full, and it was pumped out; the level was taken every ten minutes, and the HP., and the total quantity delivered was divided by the HP., the result being from 0.30 to 0.50 of efficiency. In the case of a propelling-ship he could not see why that should be very much varied if the proportions were suitable. It had been stated that one of the problems to be solved in the hydraulic-propeller was to get sufficient water to propel the vessel. In the case of the "Viper" it appeared that about five times the volume of water was discharged or pushed aft as compared with that in the "Waterwitch." That had always seemed to him a great difficulty with the hydraulic system. About three years ago his firm was asked to supply a floating-dock at a certain distant port. There was a great difficulty in re-erecting the dock abroad, and towing it was considered to be an impossibility. The question was how it was to be propelled. A screw-propeller seemed to be inadmissible from the draught of water, and from the inconvenience of a screw-propeller when docking a vessel. They therefore turned their attention to the question of hydraulic propulsion, taking the "Waterwitch's" experiments as a basis. He had a model showing how hydraulic propulsion might in such a case be advantageously employed. There were a great many compartments in the dock, and a great many pumps for emptying them. It was proposed to increase the pumps and power of the engines, and to make six apertures on each side adapted for propulsion. By that means a fair proportion of propelling area was obtained by the water discharged. The total area of all the openings was about the same as the combined area of one or two or three screw-propellers which would be necessary to propel a vessel, having a given section and capable of carrying a given tonnage, through the water. He thought that in the case of vessels of very light draught of water, and short broad vessels carrying heavy weights, the application of a screw-propeller was almost an impossibility. But while in the one case it might be impossible to apply the screw-propeller, in the other case, namely by hydraulic arrangements, it was possible to propel a vessel at a certain speed. It would be interesting if the Author would explain somewhat more fully the instrument to which he had referred for taking the pressure of the discharge at the nozzles.

Mr. EDWIN N. HENWOOD considered the hydraulic-propeller so Mr. Henwood. superior to the screw, that it would be unwise to think any money

Mr. Henwood. wasted that would enable its advantages to be brought out, and its efficiency to be developed. If a like amount of money that had been expended on the screw-propeller were to be expended on the turbine, he maintained that the success of the latter would be secured. With reference to the comparison of the "Viper" and the "Waterwitch," the former was a very objectionable structure; the "Waterwitch" was nearly as bad, but even in the latter the turbine did not have its advantages developed; it was fitted horizontally, and hence one of the streams from the discharge pipes had to be turned by a curved pipe into its proper path. The mode adopted of measuring the velocity of discharge was thoroughly unsatisfactory, as had been remarked in the Paper, since it was well known that a patent log must be carefully kept out of disturbed water in order to get a true result. Nor did he admit that the arrangement described of a pressure-plate  $1\frac{5}{16}$  inch square, supported by a more or less knife-edged lever, could be considered entirely trustworthy. With regard to the efficiency of a pump or other machine, it was needless to introduce midship section or displacement coefficient into the equation. When the designers fixed the diameter of the disk, and the number of revolutions of the engines, they had fixed the maximum velocity of discharge possible, and therefore the speed of the vessel; and no reduction of the nozzle, with the object of increasing the velocity of discharge, would materially influence the effective thrust. It appeared to him that the experiments were so devised—in error, no doubt—as to ensure no greater result than that obtained; and the Paper really seemed to lead to a double dilemma. Either the "Waterwitch" pump was effective within  $\frac{3}{10}$  of unity, or the feed was an important element in the total velocity of discharge. If the former proposition were true, then there was, under circumstances easy of repetition, no loss whatever in the pump, while in the screw there was always a large percentage of loss, without taking into account pitching, &c. If the latter were the correct explanation, not only was the result from the velocity of feed quite as great as in the "Thornycroft," but the velocity of discharge was much better for the revolutions and the disk-diameter. The revolutions in the "Waterwitch" were forty per minute, and in the "Thornycroft" four hundred and twenty-six; the diameter of the disk in the "Waterwitch" was 14 feet, and in the "Thornycroft"  $2\frac{1}{2}$  feet. The velocity of the periphery in the "Waterwitch" was 29·3 feet per second, and in the "Thornycroft" 56 feet. The velocity of discharge in the "Waterwitch" was 29 feet, and in the "Thornycroft" 37·2 feet per second. If the velocity of discharge was more than had

been observed, as seemed probable from her speed of about 10 knots Mr. Henwood. per hour, those figures would have greater prominence. He was unable to find any reason for neglecting to drive the turbine at a higher velocity. The propeller in the "Thornycroft" boat was driven at six hundred and thirty-six revolutions per minute, and the revolutions of the turbine had been reduced to four hundred and twenty-six. He could not imagine why there should be any objection to driving the turbine at a higher velocity. He should like to ask if there was any objection, and, if so, what, to working the turbine in a vertical direction so as to discharge the water underneath the bottom of the vessel? Allusion had been made to the great difficulty in utilizing the turbine for keeping down any leak. He thought the difficulties were of a very slight character, and could easily be overcome. He wished also to ask whether the speed of the circulating water from the condenser was as great as that of the pump discharge, and whether the discharge was directed aft. He thought the superiority of the turbine-propeller over the screw-propeller in the case of fouling was very great. Everyone who had gone to sea would know what would happen if the propeller broke by meeting a floating substance. In a torpedo-boat propeller driven at six hundred revolutions a minute this would often happen. In the case of the turbine there was no such source of damage.

Captain J. D. CURTIS, R.N., understood from Captain Crozier, Captain  
Curtis. who had charge of the experiments, that the performance of the "Waterwitch" was very good except when she got into a double-reef-topsail breeze. He presumed that this was on account of the pitching of the vessel. He looked upon a turbine as a kind of endless rope. Admiral Sir George Elliot had referred to the "Viper" being put 2 feet by the stern and going  $\frac{1}{4}$  knot per hour faster. The "Serapis," when put 2 feet to the stern, attained the same speed, 10 knots, with an expenditure of 50 tons of coal per twenty-four hours, as she did with 80 tons on an even keel. Reference had been made to the benefit to be derived from having an arrangement by which the screw should not foul. About two years ago the late Mr. Robert Griffiths took out a patent which he called the shield patent. This shield consisted of two plates, so arranged that they prevented the propeller acting on the dead-water, and increased the speed of a ship from 6 to 8 per cent. In addition they prevented vibration, improved the steering, and reduced the racing when the ship was pitching. The following results had been obtained from a steam-launch to which it was

Captain applied, the owner Mr. C. Bourrot, and Captain Curtis, R.N, being  
Curtis. present at the trial:—

	Without Shield.	With Shield.
Mean speed in knots per hour . . . . .	6·417	6·636
„ revolutions per minute . . . . .	289	265
„ pressure of steam in lbs. per square inch . . .	45·1	42·5

showing a gain of  $3\frac{1}{2}$  per cent. in speed, with a saving of 15 per cent. of power.

The shield was inexpensive, the estimated cost for a propeller 12 feet in diameter being only £12, and it could be put on without docking the ship. Taking the cost of marine engines at £40 per nominal HP., and allowing a similar sum for coal, also for the space occupied in the ship by the coal, and for repairs, &c., the increase of 6 per cent. in speed, to obtain which 19 per cent. more power would be required, was equivalent to an increase in the value of the ship of £1,520 for every 100 indicated HP. of the engines. In this shield the upper segment went home to the stern of the vessel; the lower segment over one-half the length of the screw from aft forward. Four trials were made with a small vessel above *Teddington Lock*, two with the shield and two without, and Mr. Robert Griffiths stated that the shield effected a saving of 15 per cent. out of the 45 per cent. which Mr. Froude asserted to be lost by the screw. How was that? When the vessel went through the water, the water must follow the ship, or the ship could not make any progress. The use of the screw detracted from the power of the water to follow the ship, and that had not been sufficiently thought of and acted upon. The shield patent must not be confounded with the cylinder, as they acted differently, the former allowing the escape of water aft. Directly the screw went down, the water came through between the apertures of the shield, and the following water flowed in to occupy the place of the water displaced by the screw. The screw did not carry the load of water round, and did not curtail the amount of in-flowing water. As the screw came up to the segment of the shield, it cut the volume of water carried round in the ordinary screw, and there was no vibration. Mr. Robert Griffiths used to say that he considered the screw a hydraulic pump, and that for efficiency it

was placed too near the ship's run. By another patent he placed the propeller two-thirds of its diameter away from the foremost stern-post, and in this way allowed the following water to act upon the ship, and did not detract from the speed of the vessel. In conclusion he might observe that aquatic birds struck out alternately with their feet when swimming, economizing power, the thrust not interfering with or obstructing the following water; and that he had heard a Yarmouth fisherman when giving directions to the builder of his smack, say "Give her a cod's head, and a duck's tail for the stern."

Mr. N. BARNABY, C.B., Director of Naval Construction, said the discussion on the Paper was remarkable for two or three reasons, one of which was that amongst those who took part in it was the gentleman who, forty-five years ago, had patented the mode of propulsion in question. Another was that for the last twenty years the Admiralty had been endeavouring to get some sort of success with the jet-propeller, and that they had not been able to point to any success. A third reason was that he believed there did not exist at the present moment any vessel in the mercantile marine employed on a passage of any kind which was propelled in that manner. Accordingly he expected that when the Paper was read he should have been called upon to explain how it came about that the Admiralty still considered it right to go on trying the jet-propeller; but he presumed, after the speeches which had been made by the gentlemen who had been influential during the last twenty years in urging upon the Admiralty the various trials of that mode of propulsion, that it would not be necessary for him to explain further why the Admiralty were desirous, after the "Waterwitch" trial, to experiment on the jet-propeller again in the boat which had been described. The arguments advanced by the gentlemen to whom he had alluded were to the effect that in ships of commerce many accidents to which the screw-propeller was liable would be altogether avoided; that many of the perils now incidental to navigation would be removed; and that navigators would have in the possession of great pumping-power a means of preserving ships and lives which they did not now possess. And they not only considered that that held good with regard to ships of commerce, but that there were special advantages to ships of war which made it still more desirable that the Admiralty should encourage the use of the new method. For his own part he did not believe in pumping-power. He believed that ships would be saved from perils of the sea by proper building, by proper division into compartments, and not by pumps; and even if they passed from the pumps with

Mr. N. Barnaby.

which they were familiar to the pumps which were supposed to be possible under the new system of propulsion, he thought they would still find that they were going in a wrong direction. But under any circumstances, whatever the advantages might be in the directions that had been pointed out, it was clear that if 2 lbs. of coal were to be burnt instead of 1 lb. for getting a certain result, it was, for the purposes of commerce, entirely out of the question to expect the jet-propeller to supplant the screw-propeller, or in any way to come into the field for practical adoption.

With reference to the contract into which the Admiralty entered with Messrs. Thornycroft and Co. for the object that had been described, the Board of Admiralty knew that they might expect a loss of about one-half the power, but they were prepared for that for the sake of the merits which it seemed to them it was possible that such a boat might have. The contract was to give the same indicated HP. as was given in the boat propelled by the screw, namely 100; they were also to guarantee that the machinery worked well; they did not guarantee any speed. As a matter of fact the machinery gave about 160 instead of 100 HP.; and they had secured a boat which he believed would be found by the trials at Portsmouth to possess so many good qualities that it was very unlikely that they would be called upon to alter the machinery back again to the screw-propeller. It was possible that some considerable improvement might be made in the pump, perhaps in the size of the nozzles, and it was possible—he hoped it might be proved to be the case—that there would be a sensibly better result than that which had been already obtained. The boat had the remarkable property of stopping very quickly, but she went astern badly and would not steer—two grave defects. The Author had clearly shown the reason for the losses which had to be sustained in that mode of propulsion; and not merely had he put before the members in a plain manner the whole of the facts in the case, but he had demonstrated this remarkable circumstance—that there was a screw-turbine, a turbine-boat it might be called, the turbine being put outside the boat, giving, with the light draught of water which it was supposed was only suitable for the hydraulic-propeller, the same speed as could be got with the screw-propeller in the ordinary way. The result of the Admiralty experiment, therefore, was a fair boat capable possibly of being considerably improved; an excellent explanation of the causes of the loss in the jet-propeller as compared with the screw; and an entirely new propeller, having admirable qualities. It might happen during the time he remained as an adviser of the

Board of Admiralty that that department might again be pressed, Mr. N. Bar-  
 as they had been during the last twenty years, to build a ship <sup>naby.</sup>  
 propelled by the hydraulic-jet. He could only say, and he said it  
 without the least hesitation, that such a proposal would have his  
 uncompromising opposition.

Mr. THOMAS A. HEARSON said that in the hydraulic experiments <sup>Mr. Hearson,</sup>  
 under discussion the short-coming of the propeller was due to  
 losses in the flow of the water through the pump and through the  
 passages, and the loss was much more than could be submitted to  
 with a continued use of the propeller. But the system had its  
 advantages, and its advocates said that if experiments were  
 continued the efficiency would be improved. It was therefore  
 advisable, before continuing the experiments or condemning the  
 system, to examine into the loss quantitatively and see how  
 much was inherent in the system and unavoidable, and how much  
 might be got rid of by improving the apparatus. The Author had  
 shown, and it might be accepted without doubt, that 1 ton of  
 water was delivered per second by means of an engine of 167 HP.,  
 with an efficiency of 0·77, which amounted to this—that every  
 pound of water delivered received an amount of energy of  $31\frac{1}{2}$  foot-  
 pounds, in other words, received a head of  $31\frac{1}{2}$  feet. Of this head  
 it might be easily calculated that only 10·4 was usefully em-  
 ployed in propulsion, and that 4 feet more was wasted in the  
 energy with which the water left the nozzle. This left 17·1 feet  
 of head wasted in some other way. If the water were imagined  
 to be taken up gradually by the action of the pump, to be endowed  
 with energy given to it by the wheel from the engine, and to be  
 delivered without any abrupt change of velocity into the casing,  
 and then delivered through the nozzles; in other words, if the  
 pumps were assumed to be acting perfectly, how much loss would  
 there be? The loss in such a case—that due to surface-friction—  
 was calculable. It might be expressed as a fraction or a multiple  
 of the energy of motion at some point in the line of motion, say at  
 the nozzle. He had calculated that in the “Thornycroft” boat  
 the fraction of the energy of motion relatively to the nozzle which  
 represented the loss by surface-friction was approximately 0·4; in  
 other words, the coefficient of resistance as employed in hydraulics  
 to express the loss of head was approximately 0·4, not less than  
 0·3 nor more than 0·5. Mr. Thornycroft had succeeded in  
 keeping it down almost to the lowest amount; the boat employed  
 lending itself to a comparatively small coefficient of resistance, for  
 the dimensions were small relatively to the power, and the length  
 of the passages were short relatively to their section. Taking

Mr. Hearson. 0·4 of the energy of motion as an accurate estimate, that would amount to  $8\frac{1}{2}$  feet of head lost by surface-friction, and there remained yet  $8\frac{1}{2}$  feet to account for. It would be instructive to work out the loss and efficiency if a value of 0·3 and also 0·5 were assumed instead of 0·4; and further to work it out for a different velocity of flow. In the "Thornycroft" boat the velocity of flow was  $1\frac{3}{4}$  that of the boat; what the Author called the acceleration was  $\frac{3}{4}$  of the velocity of the boat. If the area of the nozzle was increased 17 per cent., so that the acceleration was reduced to  $\frac{1}{2}$ , the efficiency fraction was but little altered, being increased from 0·458 to 0·465, calculated from—

$$\text{Efficiency} = \frac{2 \frac{s}{v}}{(1 + F) \left(1 + \frac{s}{v}\right)^2 - 1};$$

which was derived from—

$$\text{Efficiency} = \frac{v s}{v s + \frac{s^2}{2} + F \cdot \frac{(v + s)^2}{2}}$$

F being the coefficient of resistance, showing that very little indeed could be gained by increasing the size of the nozzle. The best efficiency worked out to 0·52, which was about the limit attainable by this method of propulsion, leaving out of account the efficiency of the mechanism of the engine. If that was good enough as compared with 0·65 of the screw, it might be continued in use; but he thought it would be admitted that it was not good enough. He wished to speak a little more of the loss of  $8\frac{1}{2}$  feet, to which he had referred, and which had not yet been accounted for, the additional loss over and above that due to surface friction. From the principle of momentum—the turning moment being equal to the change of moment of momentum imparted to the water—the energy delivered to the water by the engine per lb. of water might be otherwise calculated. It was equal to the product of the velocity of the periphery, and the tangential velocity of delivery divided by G, and equating that to the otherwise estimated amount of  $31\frac{1}{2}$  feet of head, it resulted that the water was delivered from the pump wheel with a tangential velocity of but little more than 18 feet per second, from a wheel going at a velocity of 56 feet, into a casing where the water had a much higher speed of motion, since it had on the average a velocity of  $37\frac{1}{4}$  feet. It was the eddying due to the difference in the velocities of the streams in the casing that produced the additional loss of  $8\frac{1}{2}$  feet—

a loss which it was hoped might be got rid of by a better pump. Mr. Hearson. The water came from the wheel into the casing with energy of motion given to it by the engine equivalent only to 5 feet of head. The rest of the  $31\frac{1}{2}$  feet was pressure head which took effect in increasing the flow, accelerating the speed of the water in the casing, and the remainder was dissipated in fluid eddying. If it were imagined that the streams were kept separate, and the loss for a moment suspended, then the additional  $8\frac{1}{2}$  feet would be employed in increasing the flow of the water. Increasing the flow would mean retarding the tangential delivery into a casing where the water would be going faster, which would increase the tendency to eddying. The pump gorged itself. It was easier to find fault than to suggest a remedy; but he would mention that to enlarge the dimensions of the casing might be an improvement, so that the water might flow round the casing with a smaller velocity and not be subject to the eddying described. To fix guiding blades in the passages leading to the wheel might be another improvement, so that the water would come to the wheel with a considerable moment of momentum, and less would be required to be given to it by the pump-wheel itself; or perhaps by making the blades more radial, less curved back, the loss would be less.

Captain H. E. CROZIER, R.N., observed that as the officer who commanded H.M.S. "Viper" in the experimental trials against the "Waterwitch," he begged to take exception to some of Admiral Sir George Elliot's remarks. He had never imagined that any comparison could be made between the ships. He had watched the "Waterwitch," and it appeared to him that unless she used enormous power, she had very low velocity. When off Portland on her passage to Plymouth in a single-reef topsail breeze, and in the trough of a sea, her propelling force nearly failed. Admiral Sir George Elliot had stated that the vessels "Viper," "Vixen," and "Waterwitch," on account of their rolling, were condemned as unseaworthy; and that the two former had been taken out to Bermuda and laid up there. The "Waterwitch" was laid up in ordinary at Plymouth, because she was condemned as unseaworthy after failing so signally off Portland, when she just managed to get in "by the aid of her sails" under the breakwater, was taken to Plymouth when the weather moderated, and was paid off. The "Viper," on the contrary, was employed on the coast of Ireland and at Liverpool. She steamed about 2,000 miles, exposed to uncertain weather, and then made a passage to Bermuda by sail and steam averaging 6 knots per hour. If she had been condemned as unseaworthy it was scarcely possible that the Admiralty

Captain  
Crozier.

Captain Crozier. would have allowed her to make such a voyage. At the trials between the "Viper" and the "Waterwitch" at Portsmouth, the vessels started with all their weights on board. His orders were that the mean draught of the "Viper" should be about 12 feet 4 inches. He had an idea that by altering the trim, which he was entitled to do, he should get more speed—a more solid body for the screws to work in; and, at the same time, that by taking the weights from the extremities the ship would be more lively and seaworthy. The builders' trial was 9 knots, but he obtained, as he expected, 9.4 knots per hour. Mr. Ruthven, who was on board, complained that the trial was unfair. The Admiralty decided that another trip should be taken, and he then got  $9\frac{1}{2}$  knots nearly. He had stated that at the trials the "Viper" exerted HP. up to 650, while the "Waterwitch" exerted 750. The "Waterwitch" had then part of her weights taken out, and she ran, not in such a state of efficiency as she should be in when going to sea, at 9.2 knots per hour. He thought that if a vessel so built managed to attain the speed he had mentioned, the same power would be far better exerted by the screw, which was more simple. Again, what would be the use of the "Waterwitch" in shallow water? If she went into 12 feet 4 inches depth of water, drawing 12 feet 2 inches, she would suck up mud and stones, and remain as if at anchor. As far as her propelling power was concerned, a vessel should go into action under command. Imagine the "Waterwitch" at full speed, at which alone she would be serviceable, struck by a shot, and some of her pumps getting out of order! It had been mentioned that the "Vixen" was condemned when she first went outside the breakwater. That was easily accounted for. It was because her hatches were not battened or screwed down. She nearly sank as the water got into her. Of course, when the bottom of a vessel was flat, and she had 2 feet depth of water in her, as she rolled the fires would be put out. When he took the "Viper" from Plymouth to Bermuda he was thirty days at sea, and there was very little rolling. It was not even necessary to have "fiddles" on the table to prevent the china and glass falling off. In all the 6,000 miles that he had steamed in the ship he had never seen her roll heavily.

Mr. J. R. Ruthven. Mr. J. R. RUTHVEN observed that the Author gave the efficiency of the hydraulic in the "Waterwitch" at 18 per cent., which was a force of only 4,800 lbs. to propel the ship: but to propel the ship at 9.3 knots per hour the hydraulic-propeller must have given out a force of 13,000 lbs., and so have had a total efficiency of nearly 50 per cent. of the indicated HP. A considerable difference

existed in the proportions of the boats whose trials were under comparison. The "Viper," "Waterwitch," and Swedish boats were all about five times the beam in length: while the "Thornycroft" was nearly nine times. The Author had taken the coefficients from the displacements, but when the proportions differed so much the coefficients from the cross-sections furnished a better comparison of the propellers. They were as follows:—

H.M.S. "Viper" . . . . .	424
H.M.S. "Waterwitch" . . . . .	357
Swedish screw . . . . .	277
" hydraulic . . . . .	171
"Thornycroft" screw . . . . .	362
" hydraulic . . . . .	160

By these coefficients the "Thornycroft" screw was shown to be inferior to the screw in the "Viper," still more so to the Swedish hydraulic propeller; and the hydraulic propeller in the "Waterwitch" was 123 per cent. better than the "Thornycroft."

Mr. JOSEPH BERNAYS stated that he had had considerable experience with centrifugal pumps, but he had not tried to adapt them to the hydraulic propulsion of vessels, because he considered the principle on which they acted was not suitable for that purpose. He did not say that they could not be used; the examples under discussion showed the contrary; but in matters of that kind the question was one of final efficiency or economy. It was understood with regard to the propulsion of vessels that, in order to obtain the best effect, as much water as possible must be driven towards the stern of the vessel, and with as little speed as possible, otherwise a great deal would be lost in energy. The centrifugal pump propelled a small quantity of water with great speed towards the stern. Comparing the two classes of vessel illustrated in Plate 1 the matter would be rendered clear by merely taking the area of the screw and the area of the inlet of the propeller. Judging from the load-line, he imagined that the diameter of the screw was about 3 feet; the area of the circle would be about 7 square feet; the diameter of the inlet of the hydraulic-propeller was probably 1 foot, and the proportion of 0.785 square foot to 7 square feet represented roughly the difference in the volumes of water acted upon, and showed the necessity of greater speed being imparted to that issuing from the hydraulic-propeller than to that which issued from the screw-propeller. Another disadvantage would necessarily be the position of the pump at the bottom of the vessel, where if any damage occurred it would be very difficult

Mr. J. R.  
Ruthven.

Mr. Bernays.

Mr. Bernays. to remedy it. It was stated in the Paper that floating bodies were not liable to damage the internal propeller, but in reality there was a great sucking in of water into the propeller with a certain amount of speed, which made it liable to catch floating bodies, such as wood shod with iron, and things of that kind. If these were to enter the propeller it would be liable to be damaged, and although it was in sight of everybody, it could not be got at. If in that way the casing were damaged, he imagined that without bulkheads the vessel would be lost. Something had been said about the great power for stopping leaks, but he did not see where it was to come from, or how it was to be applied, any more than with the ordinary screw propulsion. But assuming that hydraulic-propellers were suitable for the propulsion of vessels, he did not think they had had a fair chance in the arrangements that had been exhibited. Perhaps the preference should be given to the shape of the Ruthven propeller, because even in the Paper it was credited with 0.50 efficiency, whereas the more modern arrangement was only credited with 0.47 or 0.46. He did not know whether with regard to the latter any allowance had been made for the improved inlet, because if so the efficiency of the propeller proper would be still less. Many years ago he had written some letters, which were published in some of the engineering papers, with reference to the proper shape of pump-arms. He would not repeat what he had written, but would merely say that the shape of the path which a drop of water should pursue in the pump was a curve like that stated to be followed in the Ruthven propeller, but not so long; and in order to make the water take that course, the arm must wedge itself under the water near the inlet, and must be more radial as it got out, to let the water issue from the pump-disk in a more tangential direction. He spoke of the matter without any prejudice in favour of one pump more than another. The arms forming the real propelling part of the pump, their shape was of great importance. The position of the pump, as shown in the drawing of the torpedo boat (Plate 1), appeared to him to be altogether wrong. He thought that there were many places where the power of the engine given out was wasted. First, the water was raised vertically or on an inclined shoot, then it was bent at right angles and round the casing in all directions, whereas it was only wanted to move in one direction. Next it had to go through several small pipes, each bent, and finally it issued through a small jet. At every such change the water lost some of the power that had been put into it. An endeavour should

be made to deliver the water out of the pump in as broad a stream Mr. Bernays. as possible, so as to issue with the least possible speed and with the least possible loss of effect; and that, he believed, if other difficulties were not realized, could be done by placing the pump as far astern as possible. How that might affect going astern or steering he would not say, but he thought there might be methods of getting over the difficulty.

Mr. W. ATKINSON observed with reference to the intake of water Mr. Atkinson. by the inclined shoot, that the Author stated that in all previous hydraulic boats the water had been taken through a hole in the bottom, in such a way that all its velocity relatively to the ship was destroyed before it entered the pump, and that that velocity had to be restored by the pump, which involved a large waste of power. It appeared to him that there was a misconception upon that point. In the first place it must be assumed that the water in the river or the sea was stationary, and that the boat only was in motion. As the water was not in motion, it was evident that no energy had been put into it, and that there was no loss to avoid. If it was thought necessary to adopt a scoop in order to bring the water up, then it would be merely a question whether that scoop had better be used in that particular position, having already employed the power of the engine or of the machine to propel the boat; or whether it was better only that the pump itself should draw it up without the scoop. Credit was taken for the fact that in the arrangement described the relative velocity of the water and of the boat was not lost. It was, however, he thought, manifest that if the scoop were taken a little further up, and brought to the vertical line, the water would have acquired the velocity of the vessel before it entered the turbine. It had arrived nearly at that position, and it was evident that the greater portion of the velocity of the vessel would have been given to the water, and if it could not be utilized afterwards by changing its motion, all that energy would be lost. But it was not lost; it was merely the portion due to friction which was lost. If the turbine was lowered almost to the level of the bottom, the scoop done away with, and the hole for taking up the water elongated, then the lifting power of the pump would virtually do all that the scoop did, and this advantage would follow, that the motion of the vessel would not have been communicated to the water; part of the water would not have motion communicated to it, and a certain amount of loss would be avoided. It appeared to him, therefore, that the scoop was a mistake. With reference to the chamber for the distribution of the water into the vanes of the propellers, it would

Mr. Atkinson. be seen that in the model of a parallel-flow turbine exhibited there were guide blades, the object of which was to transfer the pressure of the water into rotary motion, so that when it entered into the chamber of the pump the inner portion of which was rotating perhaps at about 30 feet per second, it should enter without shock and loss of power. He should like to know why the guide-chamber had been omitted, because he had never known any turbine arrangement without one. He thought if it was desired to perfect the pump, an efficient guide-blade chamber should be introduced, and at the top an inverted cone, as was shown in the diagram of the "Waterwitch" pump, where, however, it was used for a different purpose. There would then be a second guiding power. The water which was forced in a state of great commotion into the chamber would be let off gradually in each direction. It had been stated in the discussion that the object was to drive as much water as possible astern. He thought that the object was not to send the water astern, but to propel the vessel ahead. In driving water astern, the energy due to the motion greater than the motion of the water in the sea was lost. The Paper stated that the velocity of the vessel was 22 feet per second, and the velocity of the jet 37 feet. He supposed that the difference between those two velocities was equivalent to 16 HP. lost. He believed it had been admitted by Mr. Thornycroft that it would have been better not to have had the nozzles at so great an elevation. If the water by that arrangement was raised only 2 feet it was equivalent to a loss of 8 HP. That, he thought, would indicate the direction in which there were great and unnecessary losses. If it were really necessary to have that particular form of hydraulic propulsion, he thought it would be much better to place the axis horizontally, which would no doubt get rid of a great deal of choking up of the passages, and there would be a direct flow of the water through the propeller, and economy would be the result. The axial or parallel propeller appeared to be the best. He wished to direct attention to a turbine with an inward flow, that had, he believed, yielded the highest effectiveness of any turbine ever constructed, and no doubt it could be appropriately placed in a vessel of the kind described, and would give much greater efficiency than the one under discussion. Probably one such turbine on each side of the boat would be the best arrangement. It was an American invention, and called the "Victor," being a modification of the "Hercules." The guide-blade chamber formed the outside casing, inside which was the register rate and the vanes as in an inward flow, but with the addition of another set of vanes as in a parallel-flow turbine.

Thus within a small space there was a large vane-surface, with Mr. Atkinson. the result that for the same weight a greater power could be developed than in any other turbine. Drawings of it had been given in Emerson's "Hydro-dynamics," 1882, p. 124.

Mr. W. E. RICH observed that the Author had quoted the state- Mr. Rich. ment of Lord Dufferin's Committee: "We are of opinion that the system is deserving of a more thorough trial than it has yet received"; and he thought if the Institution of Civil Engineers were called upon to advise upon such a subject at the present moment, they would have to endorse those remarks made thirteen years ago. He believed that Mr. Thornycroft, who had done a great deal in his first attempt, had not attempted to remodel the vessel or its machinery in any essential particular since his trials were made; and probably if he had to construct another vessel on the same system many points brought out by the experiments would lead him further on in the right direction. The late Professor Rankine laid down the principle which was now generally recognized, that the chief reason why very high efficiencies could never be looked for from the hydraulic system of propulsion was that another machine was introduced whose efficiency must be allowed for. Mr. Thornycroft had already obtained a speed of 12·6 knots per hour, and from a general review of the calculations given in the Paper, Mr. Rich was of opinion that 15 knots was a possible speed with the same boat and engine power. The great point in which improved results might be obtained was, he thought, in the efficiency of the fan. The Author showed an efficiency of fan and engine combined of 0·35, and then, estimating that the engines gave 0·77 efficiency in themselves, he credited the pump with the remaining 0·46. But the Thornycroft engines gave a much higher efficiency than 0·77. The traction engines tested by the Royal Agricultural Society at Wolverhampton in 1871 gave an average of 0·84, and the portable engines tried at Cardiff in the following year gave a mean efficiency of 0·825. He did not think that the engines of the Thornycroft boat were inferior to these, for probably none were made with greater care and more frictionless. Taking the Thornycroft engines, therefore, as capable of doing 0·83, the efficiency of the fans would be 0·42. As long ago as 1851 the late Mr. Appold, with the assistance of other gentlemen, determined that one of his earliest pump-fans, 12 inches in diameter and 6 inches wide, pumping 1,250 gallons a minute with a 10-foot lift, gave an efficiency of 0·68. A centrifugal pumping engine, for draining Whittlesea Mere, was erected in the following year under Mr. Appold's supervision, and twenty

Mr. Rich. years afterwards, when Mr. Rich assisted in testing it, the engine and pump were giving a combined efficiency of 0.45. A larger engine and pump, which were substituted for the originals shortly after these trials, gave 0.53 of efficiency. The Witham drainage engines and pumps, which he tested in 1873, were much more powerful, and gave a combined efficiency of 0.63, which he believed was about the highest result on record. They were throwing from 350 to 400 gallons per minute, as measured over a gauge-weir. Of course, with a centrifugal pump, as with a turbine, there was for every fall or lift one speed, and one volume of discharge at which it would give its maximum efficiency, and if the proper relations between fall speed and discharge were not strictly regulated the efficiency decreased very much. He had not examined the details of the "Thornycroft" fan analytically, nor was he in a position at the moment to offer any advice as to the best way of improving it; but from the experiments of Mr. Appold and others, he was inclined to think that a broader fan with a smaller diameter, and driven faster, would probably give greater efficiency than the fan exhibited. He also thought that if the skin of the fan could be kept further from the skin of the casing, better results would be obtained. In the construction of fans working centrifugal pumps skin-friction was an important element. In the Witham pumps, with fans 7 feet in diameter and 2 feet 2 inches wide, skin-friction absorbed a material part of the whole power. There was not only skin-friction on the circular surfaces, but there was the skin-friction of the water passing through the passages. The result was that a small fan often gave a higher efficiency than a large one. The fan of the Swedish pump resembled that of the late Mr. Appold, but its blades curved more. He had substituted a fan with blades shaped like those in the Thornycroft propeller, about nine years ago, for an Appold fan at a polder pumping-station near Amsterdam. The object in putting it in was to get the same quantity of water lifted with a lower engine speed, and this had been attained; but there was no evidence of improved efficiency in consequence of the change.

Mr. Schön-  
heyder.

Mr. W. SCHÖNHEYDER said it was important, in arranging the propulsion of a boat by hydraulic power, to have a pump of the best shape for efficiency. It appeared, from what had been done with centrifugal pumps by various engineers, that there was a great diversity of opinion as to the best form of pump both in the cross-section and in the shape of the blades. He was certain that if engineers would pay attention to what had been already

accomplished with turbines, and would remember that a centrifugal pump was only an inverted turbine, they would not have such poor results as had been from time to time recorded. The best information with regard to the centrifugal pump was, he believed, to be found in Mr. David Thomson's Paper, read on the 14th of February, 1871,<sup>1</sup> which contained an account of what had been done by the late Mr. Appold. Mr. Appold had experimented upon fans with arms of three shapes, radial straight arms, straight arms placed at an angle with the radius, and curved arms such as those in the Swedish pump. Naturally he obtained the best results with arms like those in the Swedish pump, but that was no proof that that was the best possible section. The object, of course, in constructing arms should be to give the water a gradual rotary motion, cutting through it like a knife through a piece of cheese on entering, and then gradually getting the rotary motion, and finally giving it the proper direction in which it was wanted to run. That, of course, was the reverse of what was found in turbines. In the blades experimented with by Mr. Appold, the curve was that of a screw of uniform pitch. The water being moved round by those blades at once acquired a certain rotary motion, and no increase of rotary motion was given by them afterwards. The effect was a blow to the water, which must very much diminish the efficiency, in accordance with what had been laid down by the best authorities on turbines. The "Thornycroft" wheel was a better pump than the Swedish pump or the "Waterwitch." Mr. Thornycroft had shown the path which the water took in passing through the wheel, but unfortunately he partly condemned his own work. It would be seen that the water entering the vanes took first of all a radial direction, or rather a radial direction partly backwards, and when it had passed halfway through the vanes a rotary motion was given to it gradually. From the diagram it appeared as if the vanes were made, he scarcely knew how, and afterwards the path which the water took was found; instead of which, first of all the path of the water should be determined, and then the vanes made of a proper section to give it that path. It appeared as if the first half of the length of the blades was useless, or worse than useless, because the water passed through them, and lost a certain amount of efficiency in friction. If half the inner length of the blades was cut away, he believed that better results would be obtained, motion would be imparted to the water in the same way, and there would

Mr. Schönheyder.

<sup>1</sup> Minutes of Proceedings Inst. C.E., vol. xxxii., p. 26.

Mr. Schön-  
heyder.

be less frictional resistance. He did not know how far the diagram of the "Waterwitch" pump was correct—no doubt it was correct from the data possessed by Mr. Thornycroft, but probably the delivery had been very much underrated. It would be seen that the water received a sudden blow immediately it entered the arms, which it ought not to have, and which would necessarily occasion loss. Mr. Thornycroft was correct in stating that Mr. Rigg was the first to use guide-blades for a propeller, but not in stating that he used curved guide-blades, for they were perfectly flat. The water was assumed to strike against them like a billiard ball against the cushion, and fly off at the same angle. A Paper by Mr. Rigg on the subject was read before the Society of Engineers in 1868,<sup>1</sup> and the honour of first using that method was certainly due to him. As to the possibility of a water-propelled boat ever being efficient he thought there could be no two opinions. Instead of putting a propeller into the water to act upon the whole sea, it appeared to him to be necessary to take the sea into the boat in order to get a sufficient volume to act with efficiency.

Mr. Symes.

Mr. J. P. SYMES said that reference had been made in the Paper to a floating fire-engine in which, by the advice of Mr. Brunel, one of the hydraulic-propellers was used. Some of the previous speakers had expressed an opinion that if the axle were placed horizontally it would give better results than if it were vertical; and one speaker had said it was a pity that the hydraulic-propeller had not been tried on a boat of exactly the same dimensions. Messrs. Thornycroft in their experiments had varied the dimensions of the boat somewhat, for the purpose of giving an advantage to the hydraulic-propeller. The floating engine referred to in the Paper was still in existence. It was fitted with a centrifugal pump with the axle horizontal, and was driven by means of gear, but did not exist at the present as a hydraulic-propelled boat. This vessel had been built by Messrs. Ditchburn and Mair in 1855, and the machinery, including the centrifugal pump for propelling the vessel, the steam fire-engine and the gearing for driving the centrifugal pump, were fitted by Messrs. Shand, Mason and Co., the engines being high pressure, but the results obtained were not very satisfactory as to speed. The boat was 100 feet long, 14 feet 9 inches beam, and had a mean draught of 4 feet 4 inches. The design of the boat was very favourable for a moderate speed—a much higher speed than had ever been obtained by the hydraulic-propeller. Water was taken in at the flat bottom through a square

<sup>1</sup> Society of Engineers. Transactions for 1868, p. 202.

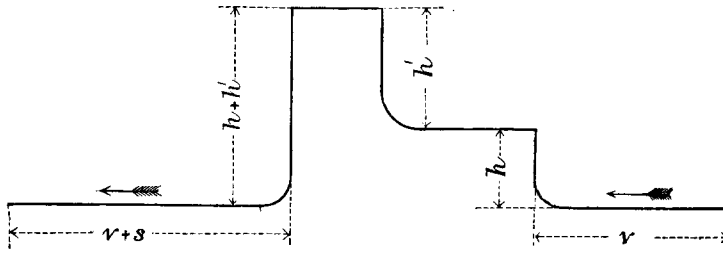
hole without any particular guide. Originally the water was discharged below the water-line, which some persons seemed to think an advantage; but some time after the jets were removed and placed a short distance above, as described in the Paper, but the difference in speed was scarcely perceptible. He was not able to say whether the jet protruded outside the vessel; if it did that no doubt would account for there being no difference in the speed, because the friction of the jet outside would be sufficient to re-act against the advantage of placing it below the water. The speed obtained by the boat, as far as he had been able to ascertain, was never higher than 6 knots per hour. There was always great difficulty in keeping the gear in order, so much so that at last the vessel was towed to fires instead of using the hydraulic-propeller. In the year 1878 the Metropolitan Board of Works, which had charge of the fire brigade, decided to have the vessel converted into a twin-screw boat. Here was a vessel of the same dimensions, with the same displacement and draught of water forward and aft, and by converting it into a twin-screw boat an opportunity would be afforded of seeing if any advantage would be gained. His opinion was that Mr. Thornycroft in altering his design had done so in favour of the hydraulic-propeller. He could not give any indicated HP., but the basis might be taken as boiler power. It was proved that the engines driving the centrifugal pump used all the steam that could be generated by the boilers; and as the boilers were left in, they had the same basis of power. Two pairs of high-pressure engines were fitted in by Messrs. A. Wilson and Co., of Vauxhall, with cylinders 8 inches in diameter and 9 inches stroke, the propellers were 3 feet in diameter and 5 feet 6 inches pitch, from two hundred and sixty to two hundred and eighty revolutions per minute were attained. On a trial with the twin-screws a speed of 10 knots per hour was obtained against 6 knots for the hydraulic-propeller with the same boat, the same displacement, and the conditions in fact almost the same. He thought this confirmed the Author's opinion and experiments that even with exactly the same boat the results would be much in favour of the screw-propellers for the power developed by the engines, so much so that the hydraulic-propeller had no chance in the competition.

Mr. SYDNEY W. BARNABY, in reply, said he thought the Institution as a body had reason to congratulate itself upon not being responsible for some of the facts and opinions that had been advanced during the discussion. So many criticisms had been made upon the Paper, that he should not reply to them all. Of course, with

Mr. Barnaby, a large hole in the bottom of the boat, it would be likely that floating material would get in, but to prevent that a grating had been supplied, and although it checked the admission of the water, it had the advantage of keeping anything out except a certain amount of sand and gravel, which the pump threw out in very shallow water. He could not approve of the suggestion that the pump should be at the stern of the boat. The reason for putting it in the centre was plain; the object was to get as big a pump as possible, and as the boat was small, the centre was the only place for it. There was a further benefit from the extra displacement obtained by the increased section of the boat abaft the inlet, shown in Fig. 7. The further forward the pump was taken the greater the advantage of that extra displacement. It had also been said that the pump would be more efficient if it had guide-blades. The fans of the pump were so adapted as to take the water without shock, and to gradually accelerate it, and he thought when the pump was so devised the guide-blades were not necessary. With respect to his coefficient of efficiency of the engines, he had taken some pains to get at a fair estimate. He had written to Mr. Rich, knowing that he had made many experiments, and he gave him a probable efficiency of about 0·80. Mr. Lilliehöök, the designer of the Swedish boat, had taken his efficiency as low as 0·72; and Mr. Brin, the Italian constructor, about the same. Mr. Wright gave 0·77 as a more probable efficiency for a marine steam-engine. It should be observed that although the "Thornycroft" engine was no doubt as efficient as any other, still in the trials the engines were quite new in the boat (after a little running no doubt they would go more freely), while those of Mr. Rich were running in their most efficient condition. It was, in fact, a trial for economy. With regard to the use of the scoop for preserving the velocity of the feed, the water had a velocity relative to the boat, equal to the speed of the boat. If the water was admitted to the pump by a hole at right angles to the direction of its motion, all that velocity was instantly destroyed. In other words, the water had a forward velocity imparted to it by the boat equal to the speed of the boat, out of which velocity no advantage could be obtained. When the entrance was a curved one, as in the "Thornycroft" boat, the water had its direction gradually changed, and it might be made to rise into a tank at a height depending upon its velocity. True it would have a forward velocity equal to the speed of the boat if the pipe reached the vertical; but it would be the original velocity with a changed direction. It might be carried any distance in the tank, but when it was allowed to fall

through a pipe curving aft it would issue with the same velocity, Mr. Barnaby. neglecting friction, with which it entered. In Fig. 14—

FIG. 14.



- $v$  = velocity of feed ;
- $h$  = head acquired by velocity of feed  $v$  ;
- $h'$  = head supplied by pump, corresponding to acceleration  $s$  ;
- $h + h'$  = total head ;
- $v + s$  = velocity of discharge due to head  $h + h'$ .

In reference to what had been said about the arms of the pump appearing to be ill-adapted to the path of the water as calculated, it should be remembered that a very slight variation in the quantity of water altered that path considerably. The pump was discharging rather more water than was intended, and it illustrated the fact that a turbine could only work at maximum efficiency in one particular set of conditions. The speakers in favour of the system of hydraulic propulsion might be roughly divided into two classes: there were first those who said they admitted that there was a considerable loss of power by the system, but looking at the great advantages which were to be obtained from it (advantages which had been described in the Paper and which he thought might be easily over-estimated), the question was what would they pay for them—would they sacrifice something in speed, or would they keep the speed and make sacrifices in armour, or guns, or cargo, as the case might be? That was a question for the naval architect and the shipowner to determine, and he had nothing to say upon it. But the other class said not only that there need be no loss from the adoption of hydraulic propulsion, but that there should be a gain. Most of those speakers had commenced by saying that they did not approach the subject from a scientific point of view, and they proceeded to lay down a set of novel and astonishing principles as a basis from which to attack the results that had been arrived at. He could only say that he had endeavoured to approach the subject from a

Mr. Barnaby. scientific standpoint. He did not know whether Admiral Selwyn was one of those who made that modest disclaimer, but one of the most important, and certainly the most misleading of those novel principles was that enunciated by him when he said that the velocity of discharge was a much more important thing than the quantity; that the quantity did not matter in the least in regard to the velocity obtained. Taking this principle as a basis, he endeavoured to show that by fixing the velocity of discharge at 37 feet per second, Mr. Thornycroft had thereby limited the speed of the boat to that obtained. He stated he was sure he could not obtain a speed of 17·7 knots per hour without a velocity of discharge of 91 feet per second. Mr. Barnaby submitted some figures in order to invite attention to that point, and to show the fallacy of the principle thus laid down.

$$\text{Efficiency of jet} = \frac{\frac{w v s}{g}}{\frac{w v s}{g} + \frac{w s^2}{2g} + \frac{f w v^2}{2g}}$$

$w$  = weight of water discharged in lbs. per second ;

$v$  = speed of vessel in feet per second ;

$s$  = slip or acceleration ;

$g$  = 32·2 feet per second.

—	“Thornycroft” Boat.	Hypothesis I.	Hypothesis II.
$w$ . . . .	2210	221	22100
$v$ . . . .	21·4	21·4	21·4
$s$ . . . .	15·85	158·5	1·585
$v + s$ . . .	37·25	179·9	22·985
Efficiency . .	0·71	0·23	0·77

At the top was the formula given by Professor Rankine for the efficiency of the jet. It had been fully described in the Appendix to the Paper; he would therefore only repeat that the first term in the denominator was useful work, the other two terms were lost work. It would be seen that in the second term  $w$  appeared in the first power only, while  $s$  the acceleration was in the second power. Therefore, if the velocity of discharge was increased the loss was increased as the square. If the quantity discharged was increased the loss increased at the same rate only. The first column showed the quantity of water acted on and the rate of discharge in the “Thornycroft” boat. The efficiency was 0·71. In the second column one-tenth the quantity was assumed, and ten times the

acceleration, the useful work, and therefore the speed of vessel, remaining the same. The efficiency was 0·23. In this case the indicated HP. would require to have been increased as 23 to 71. In the third column there was ten times the quantity and one-tenth the acceleration, giving an efficiency of 0·77 with the same propelling effect. In these hypotheses no account had been taken of friction, which added seriously to the loss as the velocity of discharge was increased. Therefore the rate of discharge was not so important as the quantity discharged, and if the whole Thames had been pumped through the boat it would only have required a velocity of discharge infinitesimally greater than the speed desired. He had heard that Admiral Selwyn had built a hydraulic boat of his own. It would have been interesting to the Institution if he had explained how he had applied his principles, and with what success. He regretted that the discussion had been confined to the old battle-field of the "Waterwitch" and the "Viper." He did not care to enter into that battle-field. If the results had proved conclusively that jet propulsion was wrong, there would have been no need for a "Thornycroft" hydraulic-boat or any other. They did not prove anything conclusively, and it was not until he came to collect all the information available that he found out why that was so. No experiments of any value had been made as to the quantity of water pumped, or as to the rate of discharge; it was therefore impossible to get accurately at what the duty of the pump was. He did not pretend that the efficiency of 0·18 was absolutely correct. As he had previously explained, he had taken that from the calculations made by Mr. Brin in a Paper read before the Institution of Naval Architects (vol. xii.). From considerations of the probable resistance of a vessel of the size and shape of the "Waterwitch," he calculated that 0·18 of the HP. which was indicated would be sufficient to give the speed which she attained. Mr. Barnaby had been induced to take those figures almost upon faith. Mr. Ruthven, junior, had, he thought, proved too much; he had endeavoured to show that the screw of the "Viper" was a great deal better than the screw of the torpedo-boats, but that was so obviously impossible that the rest of his calculations upon the same basis were probably incorrect. The new boats did really give a fair means of comparison. There had been no prejudice one way or the other, either in regard to the "Thornycroft" or the Swedish boats. In each case the designers of the screws designed the turbines, and the results had been unchallenged. The coefficients which he had given for the "Viper" and the "Waterwitch" were supplied to him by the Admiralty,

Mr. Barnaby, and they represented trials where the displacement and the speeds were as nearly as possible alike. In the Tables which Mr. M. W. Ruthven had exhibited, he had mixed up the coefficients of trials where the displacement varied from 995 to 1,205 tons, and where the speed varied as much as  $1\frac{1}{2}$  knot per hour; he had mixed them all up and divided them by the number. He would refer to Fig. 13 to show what the effect of that was. In that diagram was the curve of the coefficient of a torpedo-boat at the same displacement under different speeds. The influence of a difference of  $1\frac{1}{2}$  knot could be seen. At 9 knots there was a coefficient of 228, and at  $1\frac{1}{2}$  knot more speed it had fallen to 160. What was the value of any comparison between two systems of propulsion if carried out upon those two speeds, and if besides the displacements and forms were different? The attempt to make such a comparison betrayed a fundamental misconception of the meaning and value of coefficients of performance. Similar vessels of the same length should be tried at the same speeds and at the same displacements if a comparison of propellers was desired, and similar vessels of different lengths should be tried at corresponding displacements and corresponding speeds. By corresponding displacements he meant displacements varying as the cube of the length; by corresponding speeds, speeds varying as the square root of the length. Mr. Ruthven found a discrepancy between Table 1 and Table 2. He did not understand how the coefficient of the "Waterwitch" could be so much better than the coefficient of the "Thornycroft" boat, and nevertheless the efficiency of the hydraulic machine in the latter boat could be so much better than that of the "Waterwitch." But there was not the smallest connection between the coefficient of performances in Table 1 and the efficiency of the hydraulic machine in Table 2. If the engines of the "Waterwitch" were put upon a Thames barge, or if the "Waterwitch" herself were moored head and stern the efficiency of the hydraulic-machine might be exactly the same, but Mr. Ruthven would not like the efficiency of his system of propulsion to be judged by the coefficients of performance obtained in such a trial. Admiral Sir George Elliot had claimed that jet propulsion had never had a fair trial, and that the designers had always been hampered by the conditions imposed by the Admiralty. If he had led him to believe that they had been hampered in any way by conditions as to the draught of water he had misled him. The only conditions imposed were those stated by the Director of Naval Construction, namely that the boats should be as nearly as possible the same, that a similar boiler was to be used, and that the designers were to do

their best as far as getting speed was concerned. Every suggestion Mr. Barnaby, which they had made as to modifications in the form of the trial boat which they considered would be to its advantage had been cheerfully assented to by the Admiralty. Some of the suggestions were undoubtedly prejudicial to the efficiency of the boat as a torpedo-boat, but as it was a trial of hydraulic propulsion the designers were permitted to make even those modifications. One of them, a small one, was in the position of the boiler; it was carried out to the end of the boat, and far away from the steam impulse for ejecting the torpedoes, which was an objectionable feature, but which was considered advisable for other reasons. Another was the position of the discharges. If the discharges had been below water the noise would have been avoided, and also the serious objection arising from the large amount of white water which made the boat readily detected by the electric light at night. They had however fitted up a small centrifugal pump in a launch with the object of determining the best position for the discharges. The nozzles were attached to dynamometers, so that the reaction could be measured. The experiment showed an enormous resistance caused by the nozzle when below the surface; and it was clear that unless long discharge pipes were used carrying the water aft, as in the Swedish boat, where the nozzles were below the surface (Fig. 2), the discharge must be above water. Admiral Sir George Elliot had also said that the screw-boat should have been reduced to the same draught of water as the hydraulic. As a matter of fact the draught of the screw-boat under the keel was less than that of the hydraulic-boat, and it was only the blades of the screw revolving below the keel which made it exceed the draught of the hydraulic-boat. Admiral Sir George Elliot would cut off the legs of the screw-boat, and make it run upon its stumps, in order that it should not outrun the hydraulic. That was not fair, but even on that ground the screw-turbine propeller would beat the centrifugal pump. As had been previously stated, in a second class torpedo-boat, with 4 inches less draught of water than the hydraulic now had, nearly 5 knots additional speed per hour could have been obtained. The little boat, of which a model was exhibited, only drew 12 inches of water, and it reached the astonishing speed of 15 miles per hour with a screw-turbine propeller. A great deal of the uncertainty connected with the subject had been produced by loose statements as to the performances which had been attained by hydraulic-propelled vessels. It had been said that the "Nautilus" had beaten another vessel, the "Volunteer"; it had been stated

Mr. Barnaby. perhaps what the speeds of the vessels were, and their HP., but nothing was mentioned about the displacements, or which had the advantage in point of form. It was asserted, too, that the "Nautilus" challenged all the Citizen boats on the river, and that they declined the contest. That, however, proved nothing. He might have come before the Institution and said, "Here is a hydraulic-propelled boat two-thirds the length of a Citizen steamer, with very much less displacement, with a boiler of only two-thirds the heating surface and a weight of machinery of only  $5\frac{1}{2}$  tons against 14 tons, and yet it can run round and round any Citizen boat on the river. That would have been the truth and nothing but the truth, but not the whole truth. The whole truth was that by means of forced draught an enormous power in proportion to her size was realized. It was a great pity that statements should be put forward which proved nothing, but which led to a great deal of misconception. He thought it was most desirable that scientific questions of that sort should be treated in a more scientific manner.

Sir J. W. Bazalgette. Sir J. W. BAZALGETTE, C.B., President, said that if the Institution, as a body, did not hold itself responsible for the views which had been expressed, he felt sure that the subject had been advanced considerably by the discussion which had taken place. He had no doubt that it would lead to further experiments, and that an increase in the rate of propulsion by different modes would be the result of the consideration that had been given to the subject. The members must also feel that the Author had devoted great attention to the subject, and had made a very able reply to the many objections which had been raised in the course of the debate.