Water Jet Propulsion.

Of all the great work carried out by the Engineer, you will agree with me that the work of the Marine Engineer is the grandest, and carried out, from first to last, under the greatest difficulties.

With all our advance in design and workmanship, we are often painfully made aware of defects in our modern screw steamers.

One of the most serious is the feebleness of the power to stop a ship, and this in many cases is the cause of collisions.

Another defect is the difficulty of preventing, in some weathers, the racing of the engines, and thereby causing, or leading to breakdowns sooner or later.

Another, and perhaps the most alarming accident that can take place in a modern ship, is the breaking of the main shaft.

A broken shaft occurs so often, that one is driven to enquire the cause, when it is soon evident that the modern screw engine of great power, subject to quick reversals of motion, and to great variations of load, coupled with unknown bending strains, is eminently fitted to break shafts, no matter of what size or of what material.

The long shafting of the modern screw engine is a great source of trouble, chiefly from the movements of the hull; so much so, that the shafting may be said to be always bending, and this is one of the causes of broken shafts. At all times it is a source of anxiety to those in charge, especially in steel ships, which yield so readily to the strains to which they are subjected.

Here, then, we have the key-note to a great improvement.

We find that a land engine shaft, having a constant load, and moving in one direction, will run for a great number of years. Can this be done with a Marine Engine?

I propose to lay before you some of the properties of the Water Jet Propeller; a system of propulsion which promises to remedy most of the known defects.

It is not a novelty, indeed it is the first recorded method of propulsion after oars.

I may remark that the mode of propulsion of some of the oldest forms of marine creatures, the octopus, the cuttle-fish, and others, is by means of a jet of water forcibly discharged.

The Water Jet Propeller is a continuous jet of water, discharged in the opposite direction to that in which the ship is required to go.

There has been much confusion of ideas as to the fundamental nature of the Water Jet Propeller.

The performance of a rocket in its flight is perhaps the best illustration. Here we have an internal force, producing motion, by the unbalanced pressure of the explosive mixture.

This system of propulsion did not attract attention until it was applied by means of a pump which gave a continuous jet; and this was first done by my father and grandfather over fifty years ago.

In marine propulsion our first object should be safety; second, comfort; third, speed; and fourth, economy. I place safety first, as few will dispute the value of life.

Here we have a propeller, powerful in stopping a ship, powerful in pumping out water accumulating from a leak, able to steer the ship without a rudder; a propeller that cannot race, one that can put out any fire, and one that cannot be fouled.

The power to avoid collision, by sudden stoppage and reversal of the ship's headway, is a power of chief importance. This power has been often proved with the water jet. With higher speed it becomes more important. Even in foggy weather a vessel might safely travel when the officer could see a ship's length ahead. In passing, I may remark that the great stopping power is a proof of the efficiency of the water jet as a propeller. I need not point out the value of quickly stopping and backing in the case of a man overboard; while, with the great power of turning, there will be very little danger through loss of steerage way. For quickly stopping and reversing the motion of a ship fitted with the water jet, reversing the discharge of the jets is all that is required; and I have seen a ship propelled by the water jet, brought to rest from full speed in her own length.

The ship can be propelled astern with the same force as ahead; this is not the case with the screw. Using great speed, without the power of stopping quickly, is simply courting disaster.

Human eyesight and judgment have comparatively narrow limits ; and if the largest ship at the highest possible speed cannot be stopped to order in less than 1,000 feet, we are liable any day to hear of a great wreck.

Many good ships have been lost by collision, and probably this has been the fate of many that have not been heard of.

An iceberg, a water-logged ship, or other heavy obstacle must prove fatal in many cases. And when we consider that the most appalling wreck is yet in the future if we continue to go fast without the power of quickly stopping, this point becomes one of constantly increasing importance.

Our common road carriages and railway trains are all now fitted with means of quickly stopping. How much more important is it at sea, where the freights, human and material, are larger and more valuable.

With such a power on board a ship, all voyages would be more rapid, for the delays due to caution are considerable. Our quick train service is greatly due to the break-power.

In the water jet we have a propeller which is a means of pumping out the ship and propelling her at the same time.

The necessity for a bilge pump on board ship is so evident, and the necessity for a powerful one is also so evident, that I am surprised that it is not yet compulsory to apply more power to pump out the bilges when occasion requires.

With the jet propeller the pumping power is the whole power of the engines, and may be at the rate of 2,000 tons per minute, 120,000 tons per hour, or more.

There have been cases where a ship is said to have sunk in a few minutes after a hole has been made in her plates.

It is quite possible with the Water Jet Propeller, to arrange to keep a ship afloat, which would otherwise sink in five minutes, and not only afloat, but to propel her on her voyage ; so that she would be safe although leaking continually.

The power to stop quickly, and the power to pump out a large quantity of water should be compulsory in all steam-ships. Make the ship safe, that is the best life-saving apparatus.

With the Water Jet Propeller the ship can be navigated in the case of a damaged rudder.

In the going astern, there is no difficulty, as often occurs with a screw-ship. Again, no screw aperture being necessary near the rudder, steering by the rudder is much more certain and effective.

As regards turning, I have seen a ship, fitted with the water jet, turn on her centre, that is, in her own length. The quickest way and smallest space was by using one jet ahead and the other neutral.

The power to turn without going ahead or astern is valuable in some cases.

The movements required to control the discharge of the jets, may be made from the deck, or from the engine-room, or gear may be fitted in both places.

The discharge of the water, both above and below the water-line, has been tried, and the effect was practically the same. Hence rolling and pitching will have little or no effect, and there can be no racing due to the position of the discharge pipes, relative to the surface of the water.

So long as the bottom of the ship, amidships, is in the water; so long will the pump draw, and send out a continuous stream of water with a practically constant flow, and so have a practically constant propelling effect.

In the case of fire, one of the chief terrors at sea, the enormous quantity of water that can at once flood any part of the ship must put out any fire.

In the case of obstructions to the screw propeller, of floating wreckage, ropes, timber, or other obstacles, the value of the water jet stands out in great contrast to any propeller having a moving part outside the ship.

With the Water Jet Propeller there is no vibration. For high speeds this is of great value, not only to the comfort of the engineers and passengers, but the life of the engines and ship will be longer.

Regarding speed, there can be no limits except the power which the ship can carry.

For use with sails the water jet is most perfect, as full use of the sails can be taken, while the water jet is independently doing its work. The two modes of propulsion do not interfere with each other, as they undoubtedly do in the case of the screw.

In a head wind the loss of the screw is great; with the water jet the loss is much less, the force on the ship being greater the slower she goes.

In towing, the pull is greater for same indicated horse-power, so that in the case of a vessel on a sand-bank she could more easily get off, than with the screw. The power of quickly stopping proves this.

With the Water Jet Propeller the speed of the ship may be varied, and the direction, ahead or astern, or turning to port or starboard, may be effected with one continuous speed of engine.

There is no heavy stern frame required, so that the shipbuilder will have some saving in cost, and the ship will be relieved from the heavy weights astern.

By taking away the screw aperture the ship may be made that much shorter, or have greater displacement, and with the same fineness of lines aft.

With regard to the exact economy in smooth water as a propeller, the trials hitherto, in some cases, gave results superior to the screw, in other cases below the screw. But taking all the evidence on the best authority I know on this subject, I am convinced that in smooth water the economy of the jet propeller will probably be 30 per cent. above the screw, while in some cases at sea it may be 50 per cent.

As so much success has been attained in the few trials already made, I look for a grand future, both as regards economy and every other advantage claimed or proved.

With regard to first cost, and relative weights, I am of opinion that the weights will be about equal to the screw propeller; that is, the total weights required by the screw propeller will about equal the displacement due to the water jet propeller. The cost will settle itself, and eventually may be no greater than the screw.

The largest example of this system was in a gunboat 160 feet long, 32 feet beam, of 1,300 tons displacement, indicated horse-power 759, for 9·3 knots at deep draft, discharging 350 tons of water per minute, and the speed at light draft was 10 knots an hour. In this case two jets, each of two feet diameter, were used.

The size of the discharge tubes has been the subject of great difference of opinion. One engineer recommended two jets each of five feet diameter, for a ship which was successfully driven by two jets of two feet diameter. Another experimenter has gone to the opposite extreme, and proposed very small jets. As you know, there is a medium in all things, and somewhere between the extremes will be found the best proportion.

For the largest ship, I would have jets under two feet diameter, and have a number of them, placed where convenient. The revolutions of the pump may be anything thought best, say from 50 to 200 per minute. It is most convenient to have at least two jets, and to arrange them one on each side of the hull near the 'midships. The two jets may be supplied from one pump, or from two pumps. For large power I would have two or more jets at each side, and each jet to have a separate pump, and each pump to have its own separate set of engines. By the subdivision of the propelling power into two or more entirely independent sets of apparatus, there is hardly any conceivable accident which could happen, that would seriously affect the safety or propulsion of the ship.

The engines may be placed ahead or astern, or both ahead and astern of the main hold, so that, with a light ship, the trim would still be maintained.

A special form of ship is not required, the cargo may be stowed where thought best, and not cut up, as by the tunnel.

Whatever the popular opinion may be, I am satisfied of the great value of this propeller, and therefore bring it to your notice, and point out to you some of the more important advantages, which have been proved or are self-evident, and I believe a number more will develop themselves when further trials are made, and more particularly will the value appear at sea in the very circumstances when the greatest loss comes to the screw propeller. At the very time when the full power is wanted, the screw is at a disadvantage, whereas with the water jet, all the circumstances of the ship at sea are practically indifferent to it.

The jet propeller is a subject that insurers of ships should look carefully into ; but I leave them to look after their business, and am only desirous that we should fully discuss the subject from our point of view, that is, as engineers, both designers and sea-going—for it is a matter of life or death when the critical moment comes.

I am often distressed when I hear of a ship sinking for want of pumping power, and shocked that a vessel, otherwise good, but nearly full of water, with boilers and engines intact, gives the crew no alternative but to leave her in mid-ocean, and trust to a few poor boats.

The screw-propeller to-day has perhaps reached its limit of perfection; while, with all its success, there must still be opportunities for improvements in the water jet, so that its possibilities are greater than we know of.

If we compare the modes of action of the jet and the screw, we will see that every particle of water used by the jet is discharged in one direction, while with the screw there is a complex action, discharging water radially by centrifugal force, and many particles driven at various angles from the direction required. With the jet the centrifugal motion is used with full effect—with the screw it is entirely lost. Again, compare the water friction; the screw has surfaces moving twice the speed of the surfaces in the water jet propeller, this gives four times the loss for the screw, compared with the jet, surface for surface. Again, a well-known fact, is the increased resistance of the ship, entirely due to the action of the screw.

I believe this is the first time that the subject of water jet propulsion has been laid before those chiefly concerned. If you approve, or even wish that such an apparatus may be put into your hands, and resolve to make it a success in every way, I have no doubt it will be done. Hitherto no one has cared to look into the matter with sufficient interest, and it has long ago been cause of wonder that so many good qualities have been neglected.

The water jet propeller should be used, if only for the great pumping power. Had it no other advantage except its stopping power to avoid collisions, it is of immense value; but when it has so many advantages, it is our duty to ourselves and others to go thoroughly into the subject, and make the best we can of such a simple marine propeller.

False theories must not be allowed to obstruct the way to such a number of good qualities. The power of practical men gave us ocean steam navigation, in opposition to false theories; that is a well known instance, and there are a number of others.

It is surprising that so little has been done in this system of propulsion, yet quite a number of engineers have experimented with this propeller; but few have had the courage to try more than one or two examples, had they only stuck to it they were bound to succeed.

With comparatively light cranks, no propeller shafting, no tunnel, no unknown strains, no moving parts outside the ship, no racing, no vibration, no reversing, no easing, no priming, and no breakdowns, I look forward to a time when sea-going engineers may have more comfort and greater safety.

MR. F. W. WYMER'S REMARKS.

(*VICE-PRESIDENT.*)

Much credit is, I think, due to Mr. Ruthven for bringing this paper before the Institute.

I have known water-jet propulsion for many years, but so far I am not aware that it has been a success. It was used on the Continent, and notably in the ferries of Glasgow, but was discarded after a while working on the river.

To put it to a practical test, I would like if Mr. Ruthven could lay before the Institute a design for water-jet propulsion engines of 10,000 i.h.p. in an engine room of an Atlantic liner.

MR. J. D. CHURCHILL'S REMARKS.

(*MEMBER.*)

Mr. Ruthven's Paper appears to be a collection of statements in favour of hydraulic propulsion. It is much to be regretted that he has not given us any real information on the subject—that is, specific information regarding the trials and tests that may have been made. There are no data, formulæ, or illustrations; in fact, there does not seem to be anything tangible to discuss.

The latest development of hydraulic propulsion does not seem to bid fair for a commercial success, judging by the published reports of the trials of the lifeboat "Duke of Northumberland." It appears that this is a boat of 21 tons total displacement, with a speed of 8½ knots per hour, obtained at a cost of 170 h.p., equal to over 8 h.p. per ton displacement. For a lifeboat, this may be very satisfactory, but it certainly would not do for the Commercial Marine.

If there is a family connected, more especially, with one section of engineering than another, it is the Ruthven family with hydraulic propulsion ; doubtless, therefore, Mr. Ruthven is in a position to give us much more information than appears in the Paper.

MR. J. A. ROWE'S REMARKS.

(*MEMBER.*)

I have listened with pleasure to Mr. Ruthven's paper, and only regret that he has provided us with such meagre details. There is much in water jet propulsion to commend it to our careful consideration. It would make a splendid floating fire engine, and should enable a captain of a ship to handle her in a way not easily attained in vessels propelled by other means. But having regard to the size and number of the discharge outlets cut in the sides of H.M.S. "Waterwitch," it would appear at first sight as though a vessel's side would be riddled with holes—if a horse power of, say, 20,000 were developed. Such huge and numerous perforations in the vessel's hull amidships would weaken it, and to a great extent jeopardise the Ruthven principle.

With regard to want of efficient bilge pumps in large steamers, Mr. Ruthven has probably forgotten the bilge injection, which, if kept in order and properly used, constitutes a very powerful agent for removing water from the bilges.

I like to encourage engineers engaged in perfecting useful inventions; and as there are many good features in jet propulsion, and as Mr. Ruthven's family have spent much time and money in its development, I hope he may be spared to see it working successfully in ocean steamers. From what he has said of H.M.S. "Waterwitch," the principle is sound, and success has already been achieved on a small scale. It now rests with practical men to make jet propulsion as *economical* as propulsion by screw or paddle.

MR. F. W. SHOREY'S REMARKS.

(*MEMBER OF COUNCIL.*)

When I heard that a paper on Water Jet Propulsion was to be read, I began to wonder what sort of paper it would be, and how the advantages of the system, if any, could be shown. The paper has been very interesting to me this evening, but I have failed to see where any advantage can be claimed over that of the screw propeller by the water jet.

Mr. Ruthven speaks of the feebleness of the power of a screw propeller in stopping a vessel. Now, I consider that engines stopped and reversed by the screw are quite as effective, if not more so, in bringing a vessel up as the Jet Propeller. The only way I can account for a vessel driven by a Jet Propeller being brought up quicker than by a screw, is that she would be going so slow that it would not take much of any kind of power, to stop her. Mr. Ruthven says he is painfully aware of defects in our modern screw engines; I should like to know if the engines for driving the massive pumps for Jet Propulsion would be of a perfect type, and not subject to any defects.

He also mentions, as an illustration, the octopus and cuttle fish, as propelling themselves by jet propulsion. Now, as far as I can learn, these marine creatures are rather slow in their movements, which may perhaps well illustrate the motion also of a vessel driven by jet propulsion.

In stating that the objects in marine propulsion should be—1st, Safety; 2nd, Comfort; 3rd, Speed; 4th, Economy—I entirely agree with him; and I think, when such (if ever it should be the case) should come to pass, it will be a happy time for engineers. Unfortunately, at present, just the reverse is the case; for owners' chief study is—1st, Economy; 2nd, Speed; 3rd, Safety; and, lastly, Comfort.

It appears to me also that it would weaken and deteriorate a vessel very much, by having such a number of large holes cut in the side plating for the outlets and inlets.

Again, what a serious thing it would be for the inlets to become choked, which they must be very liable to do, especially in shallow rivers—would not the whole system then be upset?

I think also that Mr. Ruthven has over-shot the mark when he says that, taking surface for surface, the screw has a loss of four times that of the jet, due to friction. Now, it is well known what a great loss is due to frictional resistance by water passing through pipes.

In conclusion, I should have liked, and did expect that Mr. Ruthven would have given us a few more particulars of the experiments that have been made by his parents, who were the promoters of jet propulsion; I have yet to be convinced that jet propulsion is equal to screw propulsion on any of the points I have referred to.

MR. JAMES ADAMSON'S REMARKS.

(*HONORARY SECRETARY.*)

Our thanks are due to Mr. Ruthven for bringing to our notice the subject of Water Jet Propulsion. I may say that the system has been presented to my mind in a new light, and as far as I can gather, a great deal of misconception has existed, and does exist, regarding the principle on which Water Jet Propulsion is based, except amongst those few who have given the whole subject the attention which Mr. Ruthven claims it deserves.

Simultaneous with the preparation of the paper, a practical demonstration of the system was in process of being made, which goes to show that the National Life Boat Institution had been giving the subject now before us some consideration, and as a result resolved to put the system to the test.

In connection with the view which seems to have been held by many, to the effect that the forward motion of the vessel, fitted with Water Jet Propulsion, was due to the force with which the expelled water acted on the surrounding water, it appeared that a very large percentage—on this presumption—would be lost, owing to the resistance of the surrounding water. When therefore in the course of discussion the efficiency of Water Jet Propulsion was shown to be so high theoretically, it was at once apparent that the law of action and reaction on the surrounding water was not the theory at the root of the system.

There was one Ferry Boat, at least, on the Clyde, fitted with Water Jet Propulsion; in this case, I understand the water was taken in forward and ejected aft at the stern of the boat; what the percentage of efficiency to power expended was, I cannot unfortunately say, nor am I aware why the system was discarded for the screw. It is possible that Mr. Ruthven may be able to enlighten us in regard to this.

It is difficult to disabuse the mind of preconceived notions, which have gathered strength by the force of circumstances appealing in the direction of such notions; but when the foundation on which these are built is shown to be unsound, one cannot but probe deeper to find a more suitable base.

by sudden reversing from full ahead to full-speed astern, which, sooner or later, result in fractured shafting, will not occur; therefore, the machinery will cost less in repairs, and the danger of serious break-downs at sea be avoided. While on this subject, it is perhaps worthy of remark that if owners were aware of the cost and risk to them, caused by working their steamers' engines in docks and narrow waters, the practice would not be so extensively used as at present, for frequently, more damage is done to the engines by the sudden reversals, etc., in the docks, than by a long passage at sea. One other advantage pointed out would be the enormous power available for freeing the ships from water. The above are some of the advantages claimed for this system of Water Jet Propulsion, but a large number of engineers desire to have some description of the machinery, necessary to carry out this system on board the ordinary type of steamer. The author's opinion appears to be, that the weight will about equal that necessary for the screw propeller, and at present the cost will be greater; and from the example he has given of a gunboat so fitted, the dimensions of which are given as 160 by 32 and 1,300 tons displacement, this would probably give about 360 square feet of immersed midship section, and as we are informed she was driven 10 knots by two jets two feet in diameter, this is equal to one square foot of jet driving about 60 feet of immersed section; if this is correct, it follows that a steamer 40 feet beam and 20 feet draught would require four jets of not less than two feet diameter each. These dimensions are practicable, especially if the machinery is fitted aft, as is the case in most petroleum steamers, where the pipes could lead direct to the stern of the ship, fitting one pipe at each side leading forward for stopping and go astern purposes. I confess I am surprised to learn the effect of the jet above and below the water-line is practically the same, as I should expect great loss of power with a rolling and pitching vessel in a heavy sea, and should expect to find some degree of racing, with part of the load removed, as must be the case with the jets rising out of the water. We are informed the best position for the inlet pipe is at the bottom of the ship amidship; in that case, with the vessel on a sand-bank, she would not be able to exert the least power to get herself off, as the inlet pipe would soon be blocked with sand, and, therefore, her power cut off entirely; it is evident a steamer fitted with paddles or the ordinary propeller, would be in a much better position for getting herself out of a difficulty of this description. These are a few of the points, unfavourable and favourable to the system advocated by the author of the paper, and, in conclusion, we must thank him for introducing the subject, and hope, as engineers we may have further opportunities of obtaining information on this subject, especially as we are assured of so many advantages by its adoption.

MR. W. J. NOWERS BRETT'S REMARKS.

(*ASSOCIATE.*)

As to the size of the tubes for the discharge of the water, I cannot see that it matters much. With a smaller jet you will get a higher pressure; with a larger one it will be the reverse. It is probable that a higher pressure of discharge is expended more efficiently when we consider how easily water is displaced.

Although a vessel strikes upon a sand-bank the sand need not interfere with the pumps. A large volume of water would still enter the pumps and the particles of sand would be driven out from the centre of the pump or turbine by centrifugal force, and consequently they need not damage the journals or bearings of the pumps. Sand would be more likely to grind down the stern tube bearing of the screw propeller in a similar position.

Propelling a lifeboat by a jet propeller is certainly giving it a severe test. This method in the "Duke of Northumberland" has given great satisfaction, so far, during the trials that have taken place in calm and rough weather. Perhaps this little vessel will be even more interesting, as an experimental case, when the jet propeller has been brought as near perfection as the screw, and when reading its history in the days to come, we remember the days of its infancy.

MR. W. W. WILSON'S REMARKS.

(*MEMBER OF COUNCIL.*)

With regard to the efficiency of jet propulsion in stopping a ship, Mr. Ruthven says that it is able to bring up a ship in its own length. Now, I find, that in his work on Marine Engines, published in 1869, Mr. Murray, Engineer Surveyor to the Board of Trade, tells us that in the case of the "Waterwitch" this result was only obtained in twice her own length. Mr. Ruthven also states that a speed of 9·3 knots was obtained in the same ship (at least, I judge so from the dimensions), for an indicated h.p. of 759, whereas Mr. Murray says that 777 h.p. was exerted for 9·2 knots, as against 651 h.p. exerted for a speed of 9.47 knots in her sister ship, the "Viper," which was propelled by twin screws. These figures, to my mind, show that the screws of the "Viper" were the more efficient propellers. In manœuvring in circles, I find, from the same source, that the screw-propelled ship was also the most effective.

Regarding the paragraph which says that the water jet is equally as effective when being discharged in air as in water, I must confess that I cannot understand it, and should like Mr. Ruthven to give us further explanation. For my own part, I certainly think that if discharged in water (which is the most unyielding substance) the efficiency would be very much better.

Again, as to the assertion that in the case of the water jet there is less obstruction than in the screw propeller when the ship is under sail, I must say that I am at a loss to see where the difference comes in.

Taking it altogether, and with the results of experience already gained, I must say that I cannot endorse Mr. Ruthven's expectation that there is a "grand future for water-jet propulsion," for had there been any real superiority in the system, my opinion is that that "grand future" would long ere this have been realised.

MR. J. McFARLANE GRAY'S REMARKS.

(*VICE-PRESIDENT.*)

If W pounds of matter have a velocity S feet per second imparted to it in one second, the mean force applied to it during the second must be $R = W \frac{S}{g}$

Here R is the force, in pounds weight, with which the mass W resists when change of motion is being impressed upon it at the rate S. The rate at which velocity is acquired by falling bodies is 32 feet per second, and the letter *g* is here written for the number 32, denoting the rate at which velocity is acquired when every pound of matter is urged onwards with the force of one pound weight. The equation $R = W \frac{S}{g}$ denotes that the force is always, the same fraction of the weight of the mass, that, the rate of change of velocity is of the rate at which falling bodies acquire velocity. That fraction is what is expressed by S/g. (Observe that the slanting line between S and g, here, is the symbol for division, and S/g is just another way of writing S over g. This symbol is now very frequently employed to avoid inconvenience in printing.) The rate of change of velocity, S, may be either a rate of increase or a rate of decrease, the force R will still be expressed correctly by the above equation. The action is regarded as a force in the direction of the acceleration against an equal resistance in the opposite direction.

Propulsion of hulls is obtained by creating a resistant foot-hold in a mass of water driven in the opposite direction of the motion of the hull. This is better seen when the mode of propulsion is regarded as obtained by hauling upon an immersed sea-anchor far ahead, winding up the rope by a steam winch. It is then obvious that the sea-anchor has the same pull upon it that the hull has, and the length of rope wound in must be equal to the sum of the movements of the sea-anchor and of the hull. It is also clear that the work done upon the sea-anchor is all wasted energy, because, if the anchor had been ground-held, the same useful work would have been done without that waste. This is analagous to the actual slip in propulsion by paddles, by screw, or by jet.

Writing S for the velocity imparted to the anchor or foot-hold water and V for the velocity of the vessel, we see that the work done in propulsion must consist of two parts, the useful part $= V\ R = V\ W\ S/g$; the wasted part $= S\ R = S\ W\ S/g$; and the total is $= (V + S)\ W\ S/g$.

The energy of matter, W, in motion at the velocity V feet per second is $E = \frac{W V^2}{2g}$, the $\frac{V^2}{2g}$ being the height from which the mass W would require to fall to acquire the velocity V feet per second.

If, however, the instrument impressing the velocity works in the direction of its action with the velocity V, then, since the resistance must be $= \frac{W V}{g}$ it follows that the work done in imparting the velocity V must be $V R = \frac{W V^2}{g}$ or twice what is theoretically required.

Now, in the Ruthven propeller it is believed that this additional waste is in a great measure avoided, the jet acquiring its motion gradually, as in water flowing from an orifice in the side of a large reservoir under a head of pressure through a nozzle of the proper form—the contracted vein.

The letter V has been here employed as better denoting velocity, but this applies also to the velocity S of the sea-anchor, or of the slipping stream carrying our foothold of propulsion. Rankine deals with this augmentation of waste in this way:—He says the theoretical requirement is $\frac{W S^2}{2 g}$ but this may be doubled in practice, and he therefore writes the work done upon that moving mass as

$$(1 + C) \frac{W S^2}{2 g}$$

and he says that here C is a number varying from 0 to 1, according as the instrument may have worked, perfectly or imperfectly. The double is what was given as $S R = S W S/g$.

In the Ruthven propeller he points out that the water of the jet has to be picked up from rest and carried in the vessel for an instant at the velocity of the vessel. When so carried it must have imparted to it energy $= \frac{W V^2}{2 g}$ per second. Part of that must be wasted—turned into heat. Ideally, however, it is conceivable that a considerable portion of it might be recovered in the action of the propeller. Rankine writes *f* to denote what fraction of this is wasted—that is, not recovered.

The required work in the Ruthven propulsion is therefore—

$$(1 + C) \frac{W S^2}{2 g} = \text{waste in the slip water}$$

$$f \frac{W V^2}{2 g} = \text{wasted in picking up the water.}$$

$$\frac{W S V}{g} = \text{useful work, the propulsion of the hull.}$$

Writing U = useful work.
N = necessary work.
R = resistance.

We get $R = \frac{W}{g} S$

$$U = \frac{V W S}{g}$$

$$N = \frac{W}{g} S \left(V + (1 + C) \frac{S}{2} + f \frac{V^2}{2 S}\right)$$

This is the same as just stated separately, and

$$\therefore \frac{U}{N} = \frac{V}{V + (1 + C) \frac{S}{2} + f \frac{V^2}{2 S}}$$

Rankine then writes C = 0, that is he credits the system with a theoretically perfect ejection. He also writes $f = 1$; that is he assumes that the intake of the water is theoretically perfect, but the energy communicated in the intake is all lost.

The above can then be written—

$$\frac{U}{N} = \frac{V}{V + \frac{S}{2} + \frac{V^2}{2 S}} = \frac{2 VS}{2 SV + S^2 + V^2} = \frac{2 VS}{(V + S)^2}$$

Mr. R. D. Napier afterwards gave what he considered would be the maximum efficiency, and his statement agrees with the maximum derived from the above, thus—

Let $S = x V$, and substitute this for S in the above,

$$\frac{U}{N} = \frac{2 VS}{(V + S)^2} = \frac{2 x V^2}{(V + x V)^2} = \frac{2 x}{(1 + x)^2}$$

This is a maximum when its differential co-efficient = 0, that is, when $d \dfrac{2x}{(1 + x)^2} = 0$

$$\therefore \text{ When } 2(1 + x)^2 = 4x(1 + x)$$
$$\text{Or } 1 + x = 2x$$
$$\text{Or } 1 = x$$

That is when S = V, or when the actual slip velocity is equal to the velocity of the hull.

There is nothing new in what I have given you now. I have aimed at giving you just what Rankine gave in *The Engineer* for 11th January, 1867, page 25, with a few words of explanation.

MR. JOHN MILNE'S REMARKS.

(*MEMBER.*)

I was very pleased to hear Mr. Ruthven's paper to-night on Water Jet Propulsion. This sort of propulsion, to most of us being a novelty—having been so long accustomed to propulsion of vessels by the screw propeller or by the paddle wheels—we are inclined, I think, to look upon the water jet with suspicion, especially from the manner of its application. I could more easily have understood it, had the water ejected been placed below the water-line and ejected either through orifices in the ship aft or forward, or through the sides of the ship at an angle looking aft or forward, according as the vessel may be required to move ahead or astern; but, as Mr. Ruthven tells us, it is ejected above the water-line, and the centre of effect must then come within the ship, I should like to know where that would be, if he would kindly tell us. In a screw the centre of effect, of course, is the thrust; in the paddle, of course, in the plummer blocks at the sides of the ship. In pulling a boat, on the rowlock; in the jet, it must be in the pipe that is used as a discharge. The way that Mr. Ruthven has adopted of obtaining ahead and astern motion alternately, is exceedingly simple, and, if effective, would do away with a lot of machinery that we have in use at the present time, as in his application the engines would require to go one way, would not require to be stopped to reverse, and would be most useful I think, as a pump for keeping down the water in case of a serious leak. That it is expensive as a motive power for large vessels, the few experiments that have been made with it have proved, and as it is the end and aim of our engineering firms to obtain the development of the greatest power at the cheapest rate, unless the jet can keep pace with other modes of propulsion in point of economy, it will never be adopted.

It would of course be as great a danger using the water within the ship, though confined within pipes, for its propulsion, as it would likely prove to be of benefit in cases of extensive leakage.

Thanking Mr. Ruthven for his paper, I trust he will more fully explain on what and where the propelling power operates.

MR. JOHN R. RUTHVEN'S REPLY, AND EXTENDED REMARKS.

It is very interesting to know that our President took notice of some of the apparatus for jet propulsion in process of manufacture by my father about 1849. This machinery was fitted in a boat 30 ft. long, having a vertical boiler 1 ft. 10 in. diameter. This boat, the "Phenomenon," ran on the Thames in 1851 and steamed nearly the speed of the "Citizen" boats of that time.

Later on, a larger boat, the "Enterprise," was built, 90 ft. long and 16 ft. beam. This boat had a speed of nearly 10 knots.

Another boat, the "Albert," was built in Prussia, and fitted of same power as the "Enterprise." The "Albert" ran for many years as a passenger boat on the Oder.

At Blackwall, in 1866, my father built the "Nautilus," 120 ft. long, 15 ft. beam, 2 ft. 6 in. draft loaded, about 75 tons displacement; she ran 8·8 knots, with about 80 i.h.p. At times this boat steamed about 10 knots. The boiler was of same size and description as the "Citizen" boats. The "Nautilus" was passed by the Board of Trade to run as a passenger boat on the Thames, and carried many thousands of passengers successfully. To give a practical idea of the speed, this boat was often hired to attend boat races, and could easily overhaul the fastest racing boats.

This boat was also tested in a long run down the river with one of the river paddle boats, the "Volunteer," and completely beat her.

The next was the "Waterwitch." The table of results gives the relative value of the jet and screw, as compared with six vessels of same power. With the sister ships, "Viper," "Vixen," and "Waterwitch" the difference in favour of the screw is 3·8 per cent. This result is closer than can be expected between any sister ships. Comparing the jet-propelled ship with the "Philomel" class, of same length, the result of a number of trials, shows the jet 12·2 per cent. superior to the screw.

To estimate the force required to propel the "Waterwitch" at 9·3 knots and with 336 square feet midship section. Take the efficiency of the screw at 40 per cent., and suppose the ship to be as good a form for speed as the "Philomel" class, whose average co-efficient from

$$\frac{V^3 \times MS}{I.H.P.} = 298{\cdot}7$$

$$\frac{9{\cdot}3^3 \times 336}{298{\cdot}7} = 904 \text{ I.H.P.};$$

$$40 \text{ per cent. of } 904 = 361{\cdot}6 \text{ effective horse power,}$$

$$\frac{361{\cdot}6 \times 33{,}000}{930} = 12{,}830 \text{ lbs.}$$

It is a noticeable fact that the first trial of the water jet was 24 per cent. superior to the twin screw sister vessels.

I am aware that it has been said that these were bad examples of screws; but we must not forget that the screws were made to test the efficiency of the water jet. To show that they were not bad screws, I have given the results of a number of twin-screw vessels having same power as the water jet, and it is some proof of the value of the screw that they are all in this class much inferior to the water jet.

It is worthy of note that the performance of the "Waterwitch" fulfilled the expectation of the designer of the jet, and went far beyond the calculations of everyone else, and was acknowledged by the Admiralty as having performed better than they expected.

The torpedo boat, by Messrs. Thorneycroft, with the jet, did not give half the result of the screw.

The last example of jet propulsion is by Messrs. Green, of Blackwall. I here give the comparative results with the "Nautilus," to show what can be done with the jet:—

1890. Lifeboat by Messrs. Green,	24 tons,	170 I.H.P.,	8·5 knots
1866. "Nautilus," by M. W. Ruthven,	75 ,,	80 ,,	8·8 ,,

From the evidence we have, it is quite possible to get a very poor result from the jet; but I have shown that a superior result to the screw has been attained.

As some proof has been asked for on a few points contained in my paper, I will first quote Professor Rankine to show that the position of the jets with regard to the surface of the water is of small consequence. I heard him express his opinions as follows: "There is no doubt that in a theoretical point of view the turbine propeller is capable of approaching nearer to theoretical perfection than any other sort of propeller. The question that remains to be settled is, how far it is easy or possible to realise the conditions that ought to be fulfilled in order that the turbine or jet-propeller may approximate in practice to its proper theoretical performance? That is a question that can only be settled by experience. As to the advantages of being easily placed in safety, and being free from the defects that arise from being alternately lifted out and plunged into the water, those are quite clear. As regards its not losing its efficiency when the orifice of discharge is raised out of the water, I am inclined to go somewhat further than gentlemen have done. I have heard it stated that it works as well when discharged into the atmosphere as when into the water; for my part, I say it would act best of all in a vacuum; that to be plunged into the water is a disadvantage, though a very small one, and even the discharge into the atmosphere is some slight disadvantage, quite infinitesimal, indeed of no consequence at all in practice, but in a theoretical point of view it is a disadvantage. I remember very well the late Mr. Ruthven, the father of the inventor of this form of hydraulic propeller, lecturing upon the subject and demonstrating by experiment that any fluid surrounding the orifice was a disadvantage, because it impeded the issue of the jet from the orifice; and such being the action of a surrounding fluid, of course, if a body of water opposed the issue of the jet and so caused a loss of power, a body of air must do the same thing and cause a certain loss, though an imperceptible one, and, therefore, the action, no doubt, theoretically would be most efficient in a vacuum."

I here quote some remarks by Captain Colomb, R.N., in 1871, speaking of the "Waterwitch":—"A propeller is brought forward which has certain clear advantages admitted on all sides. The disadvantages urged against it are matters in dispute. The only question, it seems to me, that the Government has to consider is, whether it is worth the cost of bringing these matters which are now in dispute to the test of experiment, in order to see which side is right. If the results were favourable, all the admitted advantages would remain, and we should have a propeller perfect in every respect for the purposes of men-of-war. If the results were unfavourable, we should have spent some few thousand pounds in deciding a doubtful question, and we should have spent it uncommonly well, because you cannot do worse in important questions of this kind than to keep them hanging between heaven and earth." The same officer, speaking of the turning powers, says :—"There is always a confusion—I have observed it very widely spread—in the estimate of the laws which regulate the turning of ships, a confusion between smallness of space and smallness of time. With a ship of a certain length it is an axiom that if you diminish the time in which the ship turns, you will increase the space ; if, on the other hand, you diminish the space you will increase the time. Now, in the case of the turbine, and also of the twin screw, you apply your power so as to neutralize the propulsion, you apply it entirely in turning, you then get a turn in a very small space, but you get a longer time, and the disappointment which has occurred in the case of the turbine is in the great increase of time in the turning, because you have reduced the space so much. But the great advantage, I take it, of the turbine in its manœuvring power is not so much the power it gives you of turning in a very small space at a necessarily increased time, but it is the power it gives you of applying the whole force of your engines in a moment to stop the ship or to force her ahead from a state of rest ; and, as applied to rams, or to avoiding rams, I can conceive nothing more important than that power of immediately stopping or immediately proceeding, which neither the screw nor the paddle gives you to any great degree. I own I have been greatly surprised that a country like England, with a navy like that of England, has not put itself sufficiently to the front to thoroughly develop and thoroughly investigate the question to see whether the turbine is the propeller of the future or is not."

The following is reported as the opinion of Mr. Scott Russell, which I heard him deliver, regarding the jet, on a paper read by Admiral Elliot on Ships of War, in 1867 :—

"One word on the hydraulic propeller. He was not known as an advocate of that principle. He had known of it for two generations, and so far as he knew the relative value of propellers, it stood thus :—That the paddle wheel, the double screw, and the hydraulic propeller were, theoretically, all equally good. Out of them all they could get the same speed, and it was a mere matter of human ingenuity, in which he had infinite faith, applying each propeller so as to get out of it the special qualities and the speeds required. He would undertake to say that a hydraulic propeller, a double screw propeller, and a paddle wheel with the same power of engine, would all give the same speed, but under very different circumstances, with very different combinations, and with very different elements of construction. Therefore, he would say to Admiral Elliot, 'Go on, feel your way, puzzle your brains, get as many clever men to work as you can, and go on with your hydraulic propeller, and I promise you in the end that you will certainly succeed. I do not say that you will never get more speed than you will out of the others; I will not say that it will not take you a long time to get the same speed as the others; I won't say that you have not a deal of trouble still to take, and a monstrous quantity of ingenuity still to throw into it before you can get your wheels conveniently placed, and before you can get your large orifices for a ship of large size so constructed that your machinery shall work handily, but I promise you if you go on you will get it.'"

Regarding Mr. Wymer's remarks on the ferries at Glasgow, which some years ago were propelled by water jets, they were badly designed; there is no principle but may be misapplied, and the water jet has suffered greatly in this respect.

I hope to be able to lay before the Institute a design for a large power applied to the water jet, as suggested by Mr. Wymer.

Mr. Churchill is justified in his observation that I had given no details of trials; I now give the results of trials, and also a drawing.

Mr. Churchill's remarks as to the lifeboat are perfectly correct: the result should have been three times as good if it had been done as well as the "Waterwitch" or the "Nautilus."

Referring to Mr. Rowe's remarks, I have to say that the paper was designed to give a general idea of the water jet, and to go into detail would have extended the subject to a great length.

With regard to the number of outlets for a ship having 20,000 horse power, three on each side would be sufficient, and need not weaken the ship in the slightest degree.

As ships have sunk for want of pumping power, it is evident that all means at present supplied are not sufficient. There is no ship fitted to throw out a hundredth part of the water that can be discharged by the jet propeller.

I am obliged to Mr. Shorey for his notice of the reference to the speed of the octopus and cuttlefish. I will here quote from Wood's "Natural History," vol. 3, "Reptiles and Fishes," on this subject:—

"Argonaut, or Paper Nautilus. . . . When, however, it wishes to attain greater speed (*i e.*, than crawling or sailing), and to pass through the wide waters, it makes use of a totally different principle. As has already been mentioned, the respiration is achieved by the passage of water over the double gills or branchiæ, the water, after it has completed its purpose, being ejected through a moderately long tube, technically called the syphon. The orifice of the syphon is directed towards the head of the animal, and it is by means of this simple apparatus that the act of progression is effected. When the creature desires to dart rapidly through the water . . . it then by violently ejecting water from the syphon drives itself, by the reaction, in the opposite direction."

"Eight-armed cuttles. . . . So active that they find little difficulty in capturing their prey, or in escaping from the attacks of their enemies."

"When threatened, or if apprehensive of danger, . . . darts with arrowy swiftness from one side of the pool to the other."

"Squids.—All the squids are very active, and some species, called flying squids by sailors, . . . are able to dash out of the sea, and dart to considerable distances. Mr. Beale mentions that he has seen tens of thousands of these animals dart simultaneously out of the water when pursued by dolphins or albacores, and propel themselves through the air for a distance of eighty or a hundred yards . . . In Bennet's 'Whaling Voyage' it is mentioned that these creatures frequently leaped on the deck of the vessel in their daring flight. This squid has even been known to fling itself fairly over the ship, and fall in the water on the opposite side."

On the subject of the stopping power: with small power and slow speed we have the small power to stop the ship; and with a high speed we have a great power to stop the ship, because we have a great power to propel; therefore the distance travelled by the ships would be about the same.

The engines for jet propulsion are not subject to the defects incident to screw propulsion.

The number of outlets would not be more than three or four in the largest class of ship, and these being in the neutral axis, need not weaken the ship in the slightest degree.

I have seen sand and stones taken in and thrown out without any bad effect on the apparatus. The friction of surfaces is regarded as increasing with the speed, something like four times for double the speed, and the surface of a screw passes through the water, at about twice the speed of the water of the jets, or of the centrifugal wheel.

Mr. Adamson's remarks are evidently the result of considerable thought on this subject. I was surprised to find that the misunderstanding was so general of the effect of recoil. There can be no doubt that in the case of the circulating water being discharged at right angles to keel of ship the course will be affected.

I do not know the details of the Clyde ferry-boat, to explain why it was discarded, or the efficiency; but from the little I know of it I have no doubt from the faulty application that the efficiency was low.

I think the illustration of the rocket gives a nearer approach to the nature of jet propulsion than either the gun, or throwing weights astern.

I give a drawing showing the application of the jet to the "Waterwitch," the position of the jets are shown on the section, also the deep and light draft lines.

I also give a table of results from trials, and in addition the results of trials of the screw in four ships of better form than the "Waterwitch" and her sister ships.

In reply to Mr. Bissett's remarks, I may first say that several water jet propelled boats have been used for ordinary business, and the economy of the system is proved by reference to the table of results of trials, in sister vessels, built for the Admiralty. The necessary machinery is very simple, consisting of a centrifugal pump, having one or more cylinders to drive it. The pump is made to draw from the sea, or bilge, and to discharge through a nozzle at each side of the ship.

The impossibility to race is one of the advantages of the system, and will no doubt be found very important.

On a sand bank, sand or stones may be taken up by the pump in any quantity, and thrown out. I have seen it done without any damage or loss of effect.

To Mr. Brett, I will ask him to refer to the actual results of trials on a comparatively large scale of the screw and jet, from which he will see, in one case, the screw was 3·8 per cent. better than the jet;

and in another, the jet was 12·2 per cent. better than the screw. Taking these results together, the jet is superior to the screw by 8·4 per cent. This, considered in the small experience of the jet compared to the screw, promises remarkable success in the future.

In reply to Mr. Wilson, first on the point of stopping, I said the jet could stop a ship in her own length, because I saw it done.

In the comparison in Mr. Murray's book, he did not select the best result of the jet, while he took the best for the screw. The screw varied 60 per cent., while the jet did not vary 20 per cent. I give the results of all the trials, for comparison.

In manœuvring in circles the two ships were not tried in the same way. The jet ship was turned without any headway, thus twisting broadside through the water; the screw ship was run end on in a circle, a different manœuvre altogether.

On the subject of the nature of the action of this propeller, I can offer nothing more satisfactory than the facts, that trials have been made with the jet discharging in the air, and with the jet discharging in the water, and the results were practically alike. When the speed was 10 knots the jets were out of water, and when the speed was 9·3 knots the jets were below water.

Mr. Gray has given us a theory of the action of the water jet propeller. I have given you the practical results.

To Mr. Milne's remarks, I may say that it is entirely on the grounds of economy and many other advantages, that I have brought the jet before you, and in proof of this I may refer him to the table of trials; and although the jet is slightly inferior in one set of trials, it is largely superior in another set. The danger from a leakage of the pipes is not so great as that from steam pipes and boilers.

The propelling power operates on the pipe in the opposite direction to the face of the discharge.

My object to-night is simply to bring the subject to your notice; to go further would take more time than we have at our disposal. I wish to draw your attention to the value of the jet, and not to the details of any particular system.

In reply to Mr. Manuel on the subject of the Canal, and how it would affect the intake of the water. The inlets need not be at the lowest part of the bottom, so they would be some feet from the ground.

Of course, ships will always be liable to loss ; all we can do is to make them as safe as possible, and I believe the jet to be one of the chief means of safety.

I know that by means of compartments the ship may be made comparatively safe from sinking : but when the screw is destroyed, or cannot act, the danger to the ship is very great, whereas with a number of independent jets and engines, any damage to one would only slightly affect the propulsion of the ship.

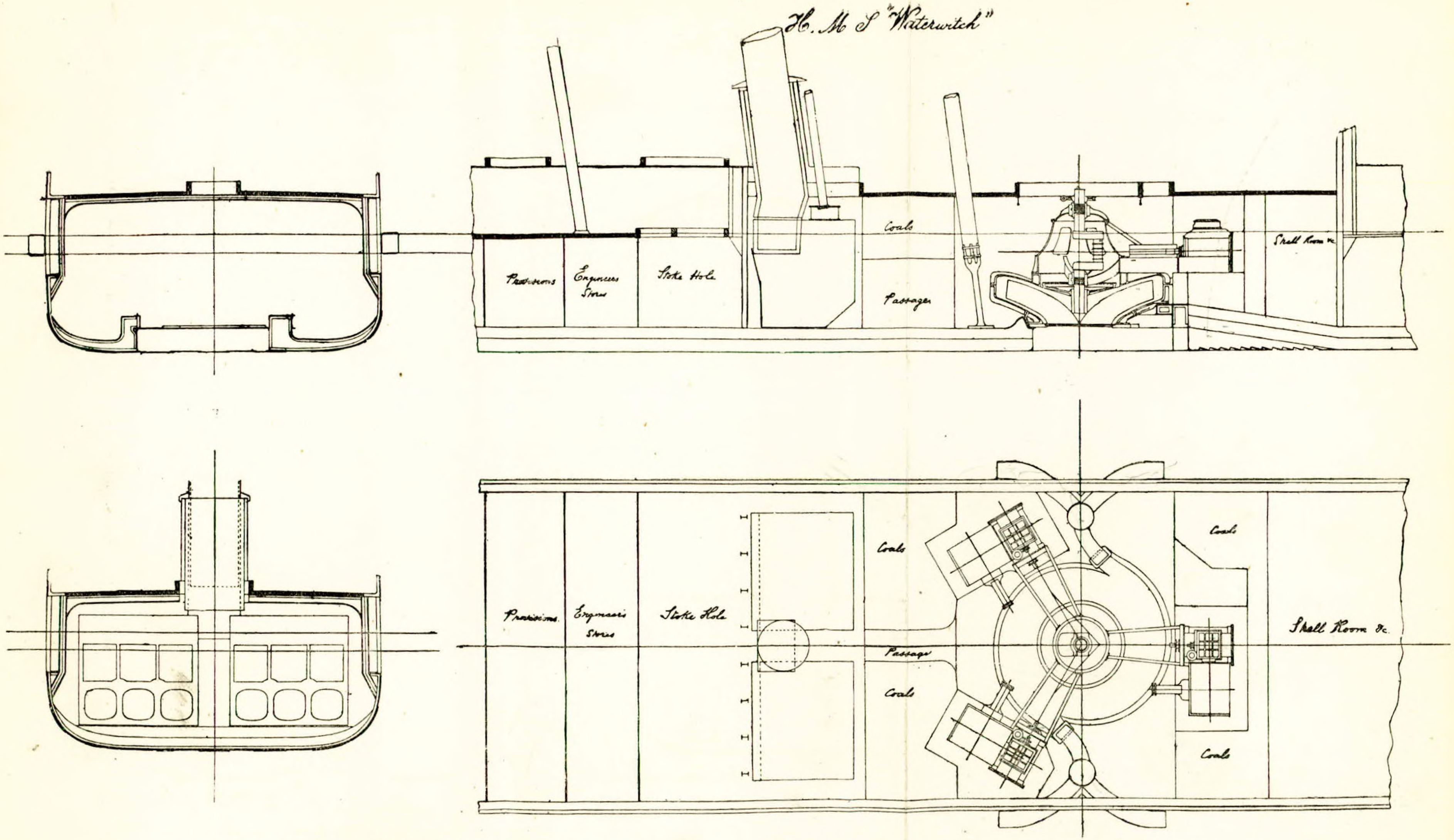
In conclusion I would thank you for the reception my paper has received, and for the discussion which ensued.

RESULTS OF TRIALS FROM $\frac{V^3 \times M.S.}{I.H.P.}$

Sister Ships, 160 × 32 ft.						Sister Ships, 170 × 29 ft.		
VIPER CLASS. *Twin Screws.*			WATERWITCH. *Water Jets.*			PHILOMEL CLASS. *Twin Screws.*		
1866 ...	9th May	... 275·6	1867 ...	1st Jan.	... 342·7	1868 ...	14th March	... 302
	18th „	... 299·9		17th „	... 327·7		20th „	... 299
	31st „	... 328·5		9th August	... 351·9		20th „	... 279
	4th June	... 321·6		28th „	... 328·7		16th April	... 274
	5th „	... 336·6		3rd Sept.	... 303·3		8th May	... 316
	5th Nov.	... 317·7		12th Oct.	... 357·8		8th „	... 311
1867 ...	2nd August	... 379·9					12th „	... 311
	5th „	... 438·5					14th July	... 329
	11th October	... 435·4					27th October	... 272
							19th Nov.	... 294
	Average ...	348·19			335·35			298·7

Difference in favour of Twin Screws, 3·8 p.c.

Difference in favour of Water Jets, 12·2 p.c.



H.M.S. "WATERWITCH," FITTED WITH WATER JET PROPELLERS. *Designed by* M. W. RUTHVEN.

Length 160 *feet.* *Beam* 32 *feet.*

Draught light, jets discharging in the air: speed 10 *knots. I.H.P.* 834.

,, *deep, jets discharging in the water: speed* 9.3 *knots. I.H.P.* 759.

PREFACE.

15 & 17, Broadway, Stratford,
November 25th, 1890.

A Meeting of the Institute of Marine Engineers was held here this evening, when an adjourned discussion on the Paper on Propellers, read by Mr. Thos. Drewry, on Tuesday, November 11th, was continued.

The Meeting on the 11th inst., was presided over by Mr. F. W. Wymer, and this evening by Mr. J. H. Thomson.

A Meeting was also held in Cardiff this evening, presided over by Professor Elliot, after he had been duly elected Chairman of the Bristol Channel Centre, by a Ballot Vote of the Local Members of the Institute.

The same Paper (Propellers) was read in the course of the evening, but time did not admit of any extended discussion after the Busines Meeting was concluded.

The subject of Propellers is a somewhat controversial one, whether considered from a practical or theoretical aspect, and the following Paper is specially commended to those who desire to follow up what Mr. Drewry has given, based upon experience and observation.

The spirit in which work is undertaken in connection with the Institute should be allied to the desire to undertake and accomplish something which will tend towards the general good, and the remarks made by the author of the present Paper at the close of the meeting, served to show that he had caught the spirit to devote time and attention to the subject dealt with from the desire to further the objects aimed at by the Promoters of the Institute.

JAS. ADAMSON,

Honorary Secretary.