Mr. STEPHENSON, President, said he had known the Author for many years, and was not acquainted with any man who had more deeply studied or was more conversant with the compound engine. He had not only for a long period engineered his own ships, but had been the consulting engineer and adviser of other large companies.

Mr. HOLT remarked that the changes which had been wrought by steam shipping in a commercial point of view had been enormous. While railway enterprise had been carried out by a few large companies, which had occupied certain districts and rendered themselves very observable, the increase in steamers had been mainly due to private individuals who owned one, two, or three vessels; the great companies which had attracted most attention had probably not moved the greatest amount of cargo, or effected the greatest amount of change.

Mr. SAMUDA, M.P., desired to refer to some points of special interest to the Institution. One was the inspection, or rather direction (as it had grown to be) of the Board of Trade and other departments, which he thought had had a most damaging effect upon the profession. Instead of advancing the science of marine engineering and naval architecture, it tended to prevent the development of the talents of engineers and to subordinate them to those who were placed in absolute authority. He did not desire to find fault with any particular department, but when men of life-long experience were the only ones who really advanced science step by step, by adding improvements in the special matters with which they were concerned, it was disheartening and discouraging to them to find either the Board of Trade, or the Admiralty or Lloyd's surveyors, laying down hard and fast lines, and compelling the registration of their decrees. The result was extremely serious, taking away from the engineering profession the power of development, and causing it to pass into the hands of those who were content in a subservient way to follow the directions of theorists, who insisted on regulating the advance that was to be made in such matters. That might appear to be an ungracious way of putting it, but he spoke as a very old member of the Institution, who had gone through every phase of shipbuilding, and had personally felt the inconvenience to which he alluded. It was a painful thing for men who had acquired a position in their profession, to be dictated to by the representatives of the different departments. He should not have spoken thus if he had not believed that it was in the interest, not only of the Institution but of the public, that a wider permission of development should be

allowed to those who had made the great work of marine engineering their study, and that they should not be interfered with by the departments who undertook to control matters of which they had only a superficial knowledge. He cordially agreed with the Author that the introduction of the screw had immensely advanced steam navigation. In speaking on that subject, he thought there was one name that could not properly be overlooked, the name of the late Mr. Brunel. His works had had the most important influence upon the department of engineering dealt with in the Paper. Mr. Brunel was literally sending his first ship the "Great Western" across the Atlantic, when lectures were being given to the public to prove the impossibility of any vessel reaching America by steam. The "Great Western" was followed by the "Great Britain," and whatever the shortcomings of that vessel might have been, there was in her the very best possible arrangement to make every particle of material of the utmost use in giving strength to the whole structure. With regard to the "Great Eastern"—which was in some respects a most unfortunate undertaking, having, he believed, cost Mr. Brunel his life—it was no doubt far in advance of the times; it had conferred great benefit on steam navigation generally, and had led up to the characteristics and features adopted in vessels of a subsequent type. Where such bold and signal departures from previous methods had been carried out, as those which had been effected by Mr. Brunel in his contribution to steam navigation, they ought to be cordially recognised. With regard to the alleged success of American wooden steamers used with a screw, he thought it was a fallacy to suppose that wooden steamers could achieve any amount of success as compared with iron steamers. A wooden steamer might be made with great advantage to be worked with paddles; but when an attempt was made to drive the power through the stern, where every fastening put in the vessel by being agitated was a continual source of destruction by enlarging the hole and diminishing the size of the fastenings, the state of things was very different from that existing in an iron vessel, which was practically a homogeneous sheet of iron. If it were not so, the latter would not stand as it did twenty years' continual rack brought upon it by the whole of the power being passed through the stern. His statement might be confirmed by what took place in the early period of screw navigation. The Government were then the only persons who used very large power through screws, but it was found so incompatible with the existence of the vessels, that it became a question of giving

them up altogether or of substituting iron vessels; and iron vessels had fully realised all the expectations formed of them, there being no longer any fear of the difficulty of passing power through the stern. With regard to the question of subsidies, he could not quite accept the view expressed in the Paper. He thought Government had done right in giving large subsidies to steamers. If they had not thus encouraged the development of steam navigation, shipbuilders could not have produced the kind of steamer that they were now enabled to construct. It was quite true, as the Author had stated, that since an opportunity had been afforded of watching what had been accomplished by subsidised lines, other steamers had been brought into competition with them, so that they would be placed at a considerable disadvantage when the subsidies had run out, since the other steamers would be able to take their place and do the same work on cheaper terms. Vessels, which would work at a profit aided by a subsidy, might be left stranded when thrown upon their own resources. The public, however, had had the full benefit of the system; they had had the advantage of steamers of enormous size and of a speed that never would have been dreamed of at so early a period. He believed that steam navigation was now far ahead of what it would have been but for the subsidies that had encouraged it.

Mr. E. Reynolds did not know whether it would be possible in the discussion to keep as clear of detail as the Author had done, because his own specialities were matters of detail to a very large extent. The Author had advocated the single engine, and had used it with great success. That was a matter of some consequence in regard to the advance of navigation, because if those engines were cheaper or more economical in working, they took up less room, and ought to be adopted. But it did not appear to him that they were the most economical arrangement, because a single engine must apply the power to a yielding medium like water by fits and starts; it must be at one portion of the revolution a force acting upon the water one-third greater than the average force, and at another part of the revolution the propeller must really be propelled by the water. It was therefore difficult to imagine that it could be the most economical arrangement; and he was strongly inclined to think that in practice it had not proved itself to be so. In his indirect connection with marine engineering he had made several screw propellers for American steamboats, and in all those cases the blades were unequally placed, two near together and the others wider apart, so that the

Americans recognised the difference of effort of the engine, and he believed that the Author had practically recognised the same evil by introducing a tolerably heavy fly-wheel. Of course the fly-wheel was not a complication, but it was ineffective weight, and it remained to be seen whether with the same total weight greater efficiency could not be secured by two engines. From the reference to the construction of the engines of the White Star ships it would appear that the Author recognised that it was partly a question of size and convenience. It was possible that the introduction of the single engine in the United States might have been to a large extent a matter of economy, in consequence of the rather crude construction to which the Americans had been driven by the excessive dearness of labour and the great cost of iron. That state of things had since been altered, and so, he believed, had been their practice in marine engineering. The designer of the engines of one of the largest lines of American steamboats had recently shown him his drawings for those engines. In some of them the English plan of two cylinders had been adopted, and in others there were four cylinders with four cranks. On the whole, it appeared to be a matter of expediency with reference to the particular circumstances. With regard to indicator diagrams, to which the Author had alluded, they were, no doubt, too much relied upon by a large number of engineers. It was possible to get almost any results from an indicator diagram; but the sole question for shipbuilders was how far a ship could be driven, and at what speed, by a certain consumption of coal. With reference to the White Star fleet, to which allusion had been made in the Paper, the first two ships were built with the intention of working with a moderate rate of expansion. They had engines with ten boilers containing twenty furnaces. One of those ships was now in existence, and she was notoriously a good one, except that she was short of steam. The actual speed of those vessels (as shown in the Blue Book on the loss of the "Atlantic") had been about 12 knots. In the next four ships with similar engines there were two additional boilers with four furnaces, in all twenty-four; and there had been an actual increase of speed almost in the direct ratio of the increased number of furnaces. That went to show that a good indicator diagram made out by a large measure of expansion was not all that was wanted. In the last two ships one-sixth had been added to the cylinder capacity and one-third to the boiler capacity, with the result that one-third more tonnage was propelled not merely at the same speed as before, but at an increased speed of $1\frac{1}{2}$ knot an hour, the latter being of itself

sufficient to account for the increase of fuel. He had no doubt that by enlarging the capacity of the cylinders of those ships better indicator diagrams could be obtained, or rather a larger amount of power could be shown upon the indicator cards by a higher measure of expansion; but he thought the performance of the ships would be materially worse. The Author had joined in the general condemnation of the interference of the Board of Trade, which was, no doubt, annoying to the enterprising and highly instructed persons who managed the most important steam trade of the world. But that was not the whole steam trade of the world; and it was impossible for the public to forget that at the time when the interference became serious they were accustomed to hear of iron ships breaking their backs at sea without warning; of such cases as that of the "London," a well-found ship, but probably overloaded, and too deep in the water for her length, lost in the Bay of Biscay, with an enormous sacrifice of life, a large portion of the crew, however, escaping in open boats. Such being the case, it was impossible to say that some supervision was not necessary; but it would be desirable that such supervision should extend more to essentials and less to details. One point to which he desired to direct attention was that some of the best class of engine-men were kept out because they did not pass a Board of Trade examination. He had no hesitation in saying that if a similar examination were required of railway engine-drivers accidents would be increased tenfold. It was as if, in engaging a turner, he should examine him as to his capability for designing a lathe, and not as to his power to make the best use of the tool before him. Another question was the substitution of steel for iron in steamships, as to which it was important to lay down good rules, but he feared that the Board of Trade would fall into the same error as other bodies had done in devising rules for the use of that material. The English Government appeared to have adopted rules taken from those of the French Government; and he saw with regret that Lloyd's had adopted similar ones. The material was to be tested by subjecting strips sheared from every plate to tensile strain, and also by cold bending to ascertain the capability of flexure without cracking (which was right enough); but they were further tested—not, as might be expected, as to the amount of indentation which a riveted seam would bear without splitting at the holes, or anything of that sort—but by heating strips red-hot, dipping them in cold water, and afterwards doubling them up. Now, surely, if there was one risk to which a ship's bottom was less liable than another it was that of getting red-

hot. Such a test could only prove the softness of the material, and that it was not of the highest strength that might with propriety be used for the purpose.

Mr. MERRIFIELD agreed with the Author in what he had stated with regard to the length of ships. As he had said, the middle part was that which carried and paid, and consequently there was a natural tendency to lengthen it. He also agreed with him that a decided limit was placed on the possibility of lengthening ships by any restriction on their size, and that for distant and rough voyages, like those across the Atlantic, it would be impossible to have with any degree of safety long ships of small size. He supposed also that there was a practical limit to the size of ships in the ports they had to serve. That was emphatically the case in the Channel passage, for it was entirely owing to the restriction on the size of the ships imposed by the ports that the service was so bad as compared with that which might be established with better ports and better ships. There was also a sharp commercial limit imposed in most trades to the size of the ships by the amount of cargo they could take in at a particular time at a particular port; he doubted, however, if that restriction applied to some of the great lines of steamers, such as those on the Atlantic ferry (so to call it) between Liverpool and New York; and it would not surprise him if at no distant period vessels as large as the "Great Eastern" crossed the Atlantic in considerable numbers. With regard to indicator diagrams, there could be no doubt that they recorded the pressure in the cylinder, and absolutely nothing else, telling nothing of what took place in the boiler or in the fire. In many cases where the application of the engine was almost direct, and where the loss of efficiency in the engine was well known, as in the Cornish pumping engine, the indicator might be to some extent a guide to the work actually done; but in the screw propeller that was very far from being the case, for the work done in the engine by no means represented the work done in driving the ship. The screw was not only an indirect propeller, but it was primarily a reaction propeller; it did not push against a rigid substance, but drove the ship by the stream of water thrown back. By virtue of the principle that action is equal to reaction, the natural tendency of things in those circumstances was that the action and reaction should tend to equality; consequently, although it was possible to do a great deal better than that, and by means of various artifices to make a propeller that did not throw away anything like half its power in the reaction, still the tendency was

that way, and the loss was great; the indicator, therefore, was no guide to the power actually employed in driving the vessel. He was not sure that he had rightly understood the Author's reasoning in one respect, but he thought he did not attach quite enough importance to the difference of pressure in engines—to working with as high a pressure in the engine as possible, and getting as absolute an economy of coal as possible. It was, of course, well known that the efficiency of an engine was theoretically limited by the ratio between the difference of temperature of the incoming and outgoing steam, and the absolute temperature of the incoming steam. Practically one temperature was fixed by that of the stoke-hole; the other, however, was to a great extent within control, and he had more hope of getting great economy from that source than from almost any other; and he valued economy rather more highly than the Author seemed to do in respect to ocean-going ships. It was true there were certain services where the amount of coal consumed bore no very large proportion to the other expenses; just as in some luxurious households the cost of bread and other necessaries of life formed but a small portion of the expenditure, so that it was immaterial to them whether bread was cheap or dear. That, however, was not the case with the public, nor was it the case generally with steam vessels, especially in long steam lines. Those, he thought, were still working very near the limits imposed upon them by the absolute economy of coal. Every pound of coal economised on those lines enabled them to drive the ships so much farther with advantage, and he believed that for the present, and at least in the immediate future, any great improvement in steam navigation was likely to be in that direction. With regard to the question of the interference of the Board of Trade, he considered it as only one small branch of a very great change that was taking place in English administrative history. Forty years ago the only ideas of Government in the country were confined to keeping the Queen's peace and raising the revenue. The only example of administrative interference was the Post Office. In 1834 the Local Government Board was established, and since then one department after another had been formed to take charge of large portions of public business which had been usually left to those who were individually concerned in working them, such as education, sewage, and other sanitary matters. Meanwhile the Civil Service estimates had increased from two millions to thirteen or fourteen millions, without counting the revenue departments, and that increase meant the actual interference of the Government with the life

and business of society. No doubt there were many inconveniences from the system adopted, but the public must now look rather to their mitigation than to any prospect of getting rid of them. England having become a crowded and wealthy nation, every one of whose members was regarded as of national importance, and it having become more and more necessary and usual to protect individuals against every species of eventuality, the public must now expect that interference to be maintained and to become more and more minute; circumstances having forced them to give up a great part of their individual liberty. No one regretted this loss of liberty more than himself. He had no doubt, however, that, in the case of merchant shipping in particular, the evil had been much aggravated by what had been forced upon the Board of Trade, namely, sentimental legislation. The Board had resisted it as long as they could—for no persons were better able than the civil servants to foresee the evil of this centralization of detail, not only to the public inconvenience, but to their own personal burthen, more especially by the enormous amount of work and responsibility forced upon them by increased centralisation and meddling with detail. At the same time, he thought that the public, and the Institution of Civil Engineers in particular, would do right to struggle for all the liberty they could get, especially the liberty of improvement, and to do their best to prevent the Board of Trade from dictating to them in matters of detail and design. The Board of Trade were not quite their own masters in the matter. When they appointed an officer to inspect a vessel, and made him practically responsible for seeing that it was safe, and insisted upon his enforcing that responsibility on the owner, there was an inevitable tendency on the part both of the owner and inspector to insist upon what they knew to be safe, and not trust to chance or skill to keep them safe—to say, "I know this invention is safe; why bother me with anything new and risky?" While such a tendency should be as far as possible checked, the Board of Trade could hardly be blamed for it, and still less its permanent officers.

Mr. C. Lamport observed that Mr. Merrifield might have gone farther in his observations as to the steam indicator; for not only did it tell nothing of what went on in the boiler or in the fire, but it told nothing of what went on in the engine driven by the steam; for it gave no indication as to the workmanship or the combination of parts. That was a serious defect. Something further was wanting, and he wondered that the Institution had done nothing to determine what constituted a real HP. Agri-

culturists, who were supposed to be a stolid and torpid class, had been the first to apply to their engines a test at once practical and scientific. They measured the exact work done by a brake, and the amount of heat that was lost by applying a pyrometer to the chimney. It would be impossible to ascertain the amount of heat generated and wasted until the amount thrown from the chimney was measured in relation to the coal consumed. It was not often that he had heard anything said by Mr. Samuda with which he could not agree; but now that that gentleman had gone out of the track with which he was so familiar, and had touched upon the politico-economical bearings of the question, he had listened to him with unmitigated astonishment. That he of all men, so enterprising and scientific, should advocate anything like a Government subsidy for the promotion of scientific or industrial progress was a problem, the solution of which he had yet to discover. To depend upon Government subsidies for the progress of steam navigation was to go back to the old principles of protection. But he could not believe that Government had ever volunteered to pay money for such a purpose. The fact was that they wanted a piece of work done, and, in a true commercial spirit, they were willing to pay for it. He wished to say a few words as to the dealing which the question of ocean steam navigation had met with at the hands of civil engineers. Within the last two months he had had the pleasure of listening to two Papers on the subject. That of the Author was most interesting and important, and had been brought forward at an opportune moment. The other paper was by Mr. Rennie at a meeting of the Institution of Naval Architects at Glasgow. Both Papers, however, dealt exclusively with the past, giving no indication of what the future might be; and he (whose capital was involved in the success of that branch of national industry) was still in the dark on that part of the subject. The Author had referred to the substitution of iron for wood, and pointed out that ships traversing the ocean under steam power could be increased in length, and that consequently the water resistance was much diminished. He thought that the conclusion was right, but that the reasons were not entirely correct. The alteration of the length had been coincident with, rather than consequent upon, the introduction of iron; and he believed the cause would be found in the fact that the introduction of steam had led to the disuse of sails. So long as ships were exclusively, or in a great measure, navigated by the pressure of wind upon a large area of sail surface, stability was a necessary element; but when the chief propelling power was de-

rived from a screw inserted within the body of the ship itself, that element of stability was no longer so necessary or important a one, and the result was that naval architects were free to follow the bent of their scientific induction, and substitute a greater length in place of a greater breadth. The law of stability was as the square of the breadth; therefore, if a vessel was to be propelled by sails, it was absolutely necessary that she should have, for a given displacement of water, a considerable lateral power of resisting the influence of the sails. He thought that in such an institution shipowners and shipbuilders might have expected to hear something as to the possible substitution of Landore steel for ordinary iron. He believed that a complete revolution as to the use of material was impending. Government had taken the question up, and had begun to use that admirable material in substitution for iron; and when shipowners had overcome the hesitation always attending the introduction of a new material, he believed they would largely substitute steel, which had a tenacity of 50 tons in comparison with iron, which might be measured at from 19 to 22 tons. Lloyd's had already taken steps in the matter, and he believed that that body, although very cautious, did not shut its eyes to all improvements, but was willing to yield to any arguments which could be urged in their favour, so far as they had a practical bearing. The object of Lloyd's was to protect underwriters whose business depended upon the safety of ships, and had nothing to do with shipowners' profits. To sum up his views in a few words: he held the propeller which, as the Author had properly stated, had initiated a revolution in steam navigation, to be a most imperfect instrument, because, from the nature of the composition of forces, it lost half the power applied by the engine. In the second place, he thought that iron should be substituted for steel. In the third place, even the compound engine could not be said to have attained anything like perfection, since it was generally acknowledged that not more than four-elevenths of the heat generated was utilised, and Mr. Scott Russell had stated that the amount did not exceed one-tenth. Were engineers to rest contented with such results—imperfect steam power, something inferior to the best material, and a bad propeller—to carry on the commerce of the world? If so, he had underestimated the suggestive skill of civil engineers, and underrated the desire for progress on the part of shipowners, and the power of shipbuilders to carry out whatever might be necessary to secure the most satisfactory result.

Mr. Scott Russell remarked that the Author had dealt with the question of what progress had been made during the last

twenty-five years in the machinery of ships, in the construction of ships, and in their commercial use and application to the earning of money. He had stated that during that period the British carriage of goods had passed from sailing ships to steamers, and that the iron ship had taken the place of the wooden one. Those were two axioms to which no one would offer the slightest objection, but that was, in fact, all that the Author had said on the very important question. In propulsion the Author simply stated that the screw had taken the place of the paddle-wheel, adding that that was nothing new, for the screw had been used before. As engineers, however, the Author said they had done much: they had introduced the compound engine, and that was a great triumph of machinery. No doubt Mr. Elder had done a great deal by the introduction of the compound engine. As the Author had said, it had been used a very long time without being highly appreciated, and for what reason? Simply because he had used it in the Pacific, where coal was dear, and economy of fuel was of great importance. Here it was not so highly esteemed, because fuel was plentiful. He remembered on one occasion saying to a gentleman, "Why do you not economise your fuel a little?" and his reply was, "The fuel costs so little that I do not care so long as one man is enough to put it in. If I required two men to put it in, I should have to economise." The Author went on to say, that even in regard to the compound engine there was no novelty and no invention. That was true, because the use of steam in two cylinders had been invented before. There was one omission in the Paper to which reference ought to be made. In his opinion the creation of the line of the Holyhead packets had been one of the most distinguished triumphs of naval architecture and mechanical engineering during the last twenty-five years. Those boats were marvellous for their speed, for their seagoing qualities, and for the admirable structure of their engines. He had had nothing to do with building them, but he had the greatest respect for all those who had had to do with the creation of that marvellous fleet, which he believed had no rival. He agreed with the Author in thinking that auxiliary engines had been a complete failure, and he was very glad that the subject had been brought forward, because it might have the effect of preventing any of those terrible losses which occurred from attempting to introduce steam and sailing together, the one to the loss of the other. The Author's remarks with regard to shipowners were very instructive and characteristic. A few shipowners, he said, had succeeded in getting a great deal of money, but for most of them trade had been

bad. Shipowners, it appeared, had worked for the public good, and not for their own. Then owners of cargoes had also suffered. Again, it appeared that whenever steamships were employed, hurry and roughness disturbed the business of the shipowner and the cargo-owner, and drove comfort out of trade. Profit and comfort had thus been driven away, and therefore, he supposed, steamships should no longer be built. The Author had stated that "the consumer, the over-idolised idol of free trade, has alone profited by steamships for the last twenty-five years," and that was "the conclusion of the whole matter." He had looked anxiously through the Paper to get the best possible instruction as to what shipowners and shipbuilders should do in future to benefit the shipowner and put money into his pocket. He was obliged to say that builders had often thought more of the pocket of the shipowner for whom they were building, than of the over-idolised public with whom personally they did not come into contact. He agreed with the Author that shipowning success depended on personal management. If shipowners were better educated, knew more of engines and boilers, could better distinguish between a good and a bad ship, and between good and bad shipbuilders, they would make more money, a little more slowly perhaps, but much more surely in the end. Much depended not only on personal management, but on personal character. When shipowners went to shipbuilders and engine-builders of known and reliable character, they always got good ships, but if they went to the last newcomer who had no character, they very often had bad ships, and then the blame was laid, not on the shipowner, but on the builders of the ships and engines. He believed that the greatest failures had arisen from the ignorance, incompetence, and cupidity of the shipowner himself. He had seen large fortunes made by shipowners, and they were men who first of all put their ships into a trade which they had already proved to be a thoroughly good, honest, and profitable one. They then went to men of the highest character to get their ships and engines made. Instead of going from one to another to get the cheapest possible ship, they kept to the old shipbuilder and engineer, on whose work they could rely. First, they would put on the trade a ship to earn a high character, and when that was done they built a second ship of a higher character, profiting by the experience of the former. They next built another which raised their character still higher, and their profits too. Then, instead of insuring their ships with insurance companies, after they had built a sufficient number they never insured at all, and

as they never lost they saved all the insurance money. Finally, having built a ship with a good character, they sold it to people of less character, who paid a large sum in addition to the value of the ship, in order to buy the character of the ship and the owner along with it. With the money thus obtained they built a newer and better one than before, and so they went on, always increasing in the excellence of their ships, always keeping to the same engineer and the same shipbuilder, always sailing their ships with the same high character, and building other and better ones for themselves. Many of the largest fortunes in the country had been earned in that way, and he would ask the members if they were not proud of such shipowners and such ships. He quite agreed with the Author that shipowners should select engines for simplicity, accessibility, and ease of repair, and should avoid engines with too many parts, and with too few parts. No better principles could be laid down for the construction of modern engines, but difficulties now and then came in the way, and one was what was called the personal difficulty. Good engines required not only an intelligent shipowner to manage them, but superior engineers to tend them. Many ships of an inferior character, with able and well-paid engineers, had done better work than was done by less intelligent owners of better ships, who screwed down the poor engineer to the lowest possible sum. He once took an old steamship and a certain amount of money in exchange for a good new steamship. He selected for her the best captain he knew, and gave him double the salary he had before, and also the best engineer he knew, giving him double the usual salary. The owners of the new ship wanted a cheap engineer and a cheap captain, and they got both. Both ships went into the same service and worked in it for two years. The old ship with the good engineer and captain earned a profit of £20,000, the good new ship with the new captain and engineer earned in the same time a loss of £15,000. With regard to the introduction of compound engines, half the amount of fuel had been saved, and that was certainly a very great step. Whereas the former engine consumed 4 lbs. per indicated HP., the compound engine consumed only 2 lbs. But although that was the case, the Author stated that compound engines were now being built of a bad character, with a very short stroke and cheese-shaped cylinders, whatever that might mean. The view of the Author evidently was that the engines should make a long stroke, and that there should be a deliberate movement of parts, also that there should be valves with great range of expansion. He agreed with the Author in every one of those points. The first and second,

however, according to the Author, were not to be obtained, and valves with a good rate of expansion were inadmissible in a screw steamer. What, then, was to be done? He was afraid it would be necessary to go back to the cheese-shaped cylinders. The Author stated that the Americans had beaten the British; and his reason for saying so was, that long cylinders and long strokes could not be obtained, in consequence of the present form of engine in screw steamers. He had seen, however, in the hands of some of the best marine engineers, methods of arranging the engine which would allow a screw steamer any length of stroke desired. No doubt a long stroke was the thing wanted in a marine engine; but accompanying it there should be a higher velocity of piston (otherwise the screw would go slower), a higher degree of expansion, and a higher pressure of steam. Low-pressure boilers ought at once to be abandoned for high-pressure boilers; and boilers should be made which would not prime. With regard to the screw, it was not always wisely placed. It would be found that there was in the stern of a ship one point where, if the screw were placed, the maximum resistance would be obtained. That point was where the stern wave just culminated and went down again. In every ship that wave, with the vessel at full speed, was at a particular point—a little farther back, he thought, than the screw was frequently put. The Author appeared to think that Government subvention had been injurious to ship and cargo-owners. He was afraid that the Author had not had a Government subvention. He thought, however, that subventions for mail ships were a great benefit to the public and to the nation. What he himself desired to see was that a great number of ships should be built fit to do special service in time of war; that in time of peace they should be subventioned, and made to carry mails; and then in time of war the Government, instead of having to build a large number of ships at a high price and in a great hurry, would have a considerable fleet at their disposal.

Mr. FLANNERY thought the Paper a very important one, as dealing with a wide subject, and expressing the opinions of a gentleman of high reputation as a marine engineer; but he thought that, if the Author had given some of the reasons on which he had founded his theories, members who came to learn would have learned even more. With regard to compound engines, the Author appeared to admire greatly the design and boldness of the Americans, and thought the single-cylinder engine might be more economical and suitable for general purposes than those in which expansion was conducted in two cylinders; but he had

shortly afterwards expressed an opinion that higher pressures must eventually take the place of those at present in use. There seemed to be a difficulty in reconciling those two statements. The chief reasons for adopting two cylinders were that the impact could be reduced at the beginning of the stroke by having a small piston with a high pressure, and a large piston with a low pressure per square inch; and that the range of temperature could be reduced through which any single cylinder passed, by admitting high-temperature steam into one cylinder, and a lower temperature steam into another. Those reasons were undoubtedly increased, in a large degree, if the pressure and the temperature of the steam were increased; and if engineers were driven to the use, for general purposes, of two cylinders for the present pressure, how much more would they be driven to the use of three or four cylinders for very much higher pressure? With regard to the single-crank engine, the Author had found no difficulty in dealing with it. Any one who went into the engine-room of a steamship fitted with a two-cylinder engine and two cranks, was struck by the fact that a large amount of space above the engine was apparently wasted, having no other use than that of ventilation. The Author, he believed, was the first engineer and shipowner who attempted to reduce that disadvantage. By the engine with two cylinders placed vertically one above the other, and working with a single crank, he had reduced the amount of space necessary for a given HP., and had also, he believed, reduced the weight of the engine to a slight extent, at the same time increasing the cargo-carrying capacity of the ship. At one place with which he was acquainted in the North of England that method was coming more and more into use. He had called attention to the matter, hoping that the Author would be able to say something as to the amount of gain secured by the use of those engines. With reference to the indicator, in face of the facts that the Admiralty had entirely abolished the term "nominal HP." and purchased the whole of their machinery for the Royal Navy upon the criterion of indicated HP., together with the specification of proportions, and that Lloyd's Committee had issued a circular to the chief marine engineers of the kingdom, asking their opinion upon the question of nominal HP. and the mode of calculating it, because they found that a great many shipowners overrated or underrated, according to their commercial requirements, the nominal HP. of their ships, it was startling to find the Author saying that indicated HP. was a criterion of no value in the purchase or comparison of engines. He ventured to think that if, with the

indicated HP., there was a strict specification of proportions and sizes of parts, that would afford a very excellent comparison between engines of different powers and different types. There was one important remark in the Paper with reference to boilers. About four years ago the late Mr. Ward Hunt aroused the deepest consternation as to the state of the boilers in the Royal Navy, which he said were decaying rapidly. It was, he believed, an admitted fact that the lives of boilers with modern compound engines and surface condensers in the Royal Navy had been much shorter than the lives of those of the old low-pressure type. In contrast with that the Author, a gentleman of great experience, had come forward and stated that the boilers in the mercantile marine lasted as long now as ever. He hoped he would be able to state why there was such a marked contrast in the two cases. A comparison had been made by him between marine and locomotive boilers. He stated that a boiler of the locomotive type would be allowed to carry passengers working at a pressure of 120 lbs., but that, if the same boiler were on board ship, 70 lbs. pressure would be the utmost allowed by the Board of Trade. Taking into consideration the surrounding circumstances, the contrast was not a violent one. The boilers of a ship were sometimes under steam for forty or forty-five days; but a locomotive boiler, after being under steam for seven or eight hours, was sent into the shed and inspected. Again, the chief engineer on board a sea-going ship did not, as a rule, possess the same attainments as a superior officer of the locomotive department of a railway. He was aware that the examiner-in-chief of engineers was doing his utmost to increase the technical knowledge of sea-going engineers, but notwithstanding all his efforts, the scientific attainments of those men were not great. Locomotive boilers, moreover, with regard to the generation of steam, were much more under control than marine boilers. In shutting off steam from a locomotive engine the blast was stopped, and the generation of steam was practically stopped, or at all events reduced to a large extent; but there were no such means of reducing the generation of steam in a marine boiler. He could not conclude without paying a tribute of respectful admiration to the manner in which the Paper had been written. It did not contain a single allusion to the way in which the Author himself had contributed to the progress to which he had referred. Knowing the value of his contributions, not only as an engineer, but as a shipowner, the meeting could not but feel that he had acted both modestly and wisely in not referring to the matter at all in his Paper.

Mr. T. GRAY observed that the Paper raised questions of the greatest importance to commerce, and therefore of vital interest to the chief commercial country in the world. The Author himself had played no unworthy part in contributing to that greatness, and his own fleet of steamers—should he say in consequence or in spite of the interference he condemned?—now floated as one of the nation's proudest evidences. No one was more competent than the Author to fulfil the duty that he had imposed on himself. He quite concurred in the remarks of Mr. Flannery with regard to the extreme modesty of the Author, who had prepared for the archives of the Institution a statement which would be referred to centuries hence, when what was now too near to be appreciated at its full value would have passed into history. The Author had given prominence to the name of Elder, and thus paid a tribute to the memory of one whom all acknowledged as the greatest leader in a most remarkable reformation of the steam-engine. He did not propose to follow the Author through his Paper, but would confine his observations to two of its features: first, that which had cast doubt upon the wisdom of State interference with the concerns of daily life; and, secondly, that in which the Author prayed the Council of the Institution to use its powers of intercession between the Board of Trade and that part of the British public whose business or pleasure compelled them to "go down to the sea in ships." He was entirely at one with the Author in his views concerning the unwisdom of interference with the details of the construction and equipment of ships—especially when, as in the present case, that interference lessened, and perhaps destroyed *in toto* the responsibility which ought to rest on the shipowner. He did not think that the way to insure safety was to remove responsibility from any one, but that the very reverse of that method should be adopted. The question resolved itself into this, not only with regard to ships but with regard to all industrial occupations: Was the State to become mother and nurse and keep industry in swaddling clothes, or was it to be chief policeman and to punish evil-doers? Twelve years ago he had expressed his views on the subject in a Paper read at the Society of Arts, and those views then and subsequently expressed had led the Author to assume that regulations, which were framed solely with a view of carrying into effect a trust imposed on the Board of Trade by the nation, were framed with the unworthy and ridiculous motive of proving the exceeding irkfulness of inspection. He hoped that the Author would, on reflection, give the framers of the rules credit at least for honesty. The observation he had made on that point

was the only unkind act he had known him commit. He knew no one inside or outside the Board of Trade who did not regard the excessive details with disfavour. He was at one with the Author in his wishes. He took his place in the same boat with him, and trusted that, by pulling together, they would come to some common understanding. He wished to remark, that the legislature by express enactment required the Board of Trade to certify that boilers of steamships were safe for twelve months, and to fix the working pressure: and that the instructions of the Board as to the strength of boilers were founded on the teaching of the late Sir William Fairbairn and Professor Rankine. It was not the Board of Trade that was attacked when it was stated that boilers should not have the factors of safety of 8 and 6: it was those professors and their disciples. They had been taught that boilers ought to have factors of safety of 8 and 6; and if the Institution and the Author, or any competent authority would tell the Board of Trade and the nation that the teaching of Fairbairn and Rankine was wrong, and that those factors were no longer necessary, he had no doubt that the Board of Trade would be able to alter their instructions.

Mr. THORNYCROFT desired to make a few remarks on the comparison of single engines with engines having more than one crank. When two cylinders were placed one above the other, they were, for his purpose, single engines. The Author had laid stress on the value of single engines, but had not shown in what their economy consisted. As a shipowner he was not interested in the indicated HP. of engines, but in how far the engines would propel the ship with a certain amount of coal. Mr. Thornycroft believed that Mr. Froude was now bringing out a dynamometer by means of which the work done in the screw shaft might be accurately estimated; and when it became the custom to measure the power of the engines by the work actually available in the screw shaft, it was probable that the Author's estimate of the value of indicator diagrams might be more general. He did not think that the Author intended to discourage the use of the indicator; but he understood him to refer to short-stroke engines having great weight on the journals. When there was a pair of engines, the crank shaft being somewhat flexible compared with the frame, the forward engine not only exerted a pressure on the journals of its own bearings, but, by the twisting of the after crank pins, a great strain was also thrown sideways on the after journals, and it has been shown that the amount of power delivered to modern war ships was only a small percentage of the work done by the steam

in the cylinders. In the American paddle steamers the hulls were too shallow to be of favourable form for easy or economical propulsion, so the engines must give a high duty in work done on the ships to give the favourable results stated by the Author. He considered that the small crank pin, single engine and valve gear working with a very small friction, might be taken as contributing greatly to the high efficiency. His object in rising had been to direct attention to the important bearing Mr. Froude's dynamometer had on the subject of the Paper, and to express his conviction of the great value of so perfect an instrument for measuring the available power for propelling a ship.

Mr. T. W. TRAILL said the remarks in the Paper, as to boiler purposes, were of such a nature that it was to be regretted that more facts and less general imaginative ideas had not been stated. This would have been fairer to all parties, as the objections could then have been answered, and every one would probably have been more benefited by the discussion which would have arisen. Engineers had frequently lofty flights of imagination. Their grand ideas might take various forms and might be instructive and useful, and it would seem desirable that this should be so; but although these ideas might be novel, unless they could be established by facts, they would probably not do much to reward their Author or benefit those interested in engineering matters, and this, irrespective of whether or not the interest of the Author arose from a love of his profession, or from the fact that he was in a pecuniary way connected with engineering, or what was of more consequence, be the means of saving life. He would then merely state a few facts, as such were without doubt what in the present case would seem to be desirable, and he could only remark, that if the pressures alluded to by the Author were obtained by anything like the method which he had on a former occasion advocated in print, that the most recent experiments on the bursting strength of actual boilers most clearly showed that the real strength of the boiler was not that which would be attained by adopting the ideas of the Author, so far as Mr. Traill was in possession of them. The two cases which he should allude to were circular boilers, one of them 11 feet 6 inches in diameter, in which the percentage of material left in the plate was 56, and thickness of plate at fracture $\frac{11}{16}$ inch; and one of 11 feet 3 inches in diameter, in which the percentage of materials left in the plate was 53, and thickness of plate at fracture $\frac{3}{4}$ inch. As they both went by the plate giving way he would not enter into any more details. The first actually burst at a pressure of 195 lbs., the second at 230 lbs.

Now he would ask the Author if he would state the factor of safety he would adopt, and whether he still admitted that it might be taken as a postulate that six was a proper factor for a boiler, as the boilers in the cases Mr. Traill had given, would, by the Author's ideas, have had factors of safety of about 5·9 and 7·1 respectively, whereas the real factors of safety were 3·9 and 3·8 respectively. In one case the boiler burst within $\frac{7}{10}$ lb., and in the outer case $\frac{3}{10}$ lb., of what the calculation by book showed they ought to have burst, and however much the Author might object to the method, he maintained, that up to that time there was not a more correct one. Adopting the plan advocated by the Author in a Paper issued some time since, it would be found that, in the first case, the calculating bursting pressure would be about 298 lbs., or 52 per cent. above the actual bursting pressure, and in the second case it would be about 426 lbs. or 85 per cent. above the actual bursting pressure. Further comment on such a method would be unnecessary. The apparent discrepancies in the two cases arose from the fallacy in the method advocated by the Author. He could state more facts, but the figures which he had given most clearly proved that the principles laid down in the book which was found to be not unamusing were based on facts and not on fiction, and in dealing with steam, engineers were not, he held, justified in dealing with anything but facts.

Mr. D. Mac Iver, M.P., said that for many years he had been interested in shipping as a steamship owner, and he took pride in steamships, not merely for what they made in the way of profit, but in a mechanical point of view. The Paper in all its essentials deserved the approval of those who had had an extensive experience of steam shipping, but there were a few points in it on which he differed from the Author, and some other points which he thought were not quite so exhaustive as the Author apparently intended them to be. He had no desire to defend the Board of Trade in everything; he knew that they were not always right, but he thought that on the subject of boilers the Author was still further wrong. He would ask what had been the result in those vessels in which the Board of Trade standard of efficiency had been departed from? He wished to mention the case of four vessels, two of which belonged to personal friends of his; in the third he was himself at one time a part owner; the fourth was a tug, whose owner he did not know. Three of those vessels had Board of Trade certificates, and as long as they possessed them they went safe; but a time came when, according to the Merchant Shipping Act of 1876, vessels were allowed to carry twelve pas-

sengers without that certificate, and when the people who had the management of those vessels thought they might disregard the Board of Trade conditions in reference to boiler pressure. In each case there was an explosion, with serious loss of life. The conditions under which locomotive and marine boilers worked were (as had been pointed out) very different. The marine boiler went away for a long time; ships did not carry too many engineers; and, owing to sickness or other causes, a boiler might be in charge of less competent hands than the owner intended. He thought that the margin of safety should be larger at sea than on shore. His principal object in rising was to ask for the support of the Institution of Civil Engineers with reference to matters of legislation. In the House of Commons there were very few persons who had any practical acquaintance with the management of steam shipping. On the Conservative side he was absolutely the only steam shipowner, other than limited liability proprietors, and those on the Liberal side could be counted on the fingers of one hand. He thought that recent legislation, however well intended, had really proceeded very much in the direction illustrated by Mr. Gray's speech. The Board of Trade, it was quite evident, entirely failed to realise how far they might usefully supervise matters connected with shipping; and, without having any intention of doing so, they seriously troubled, harassed, and annoyed the shipowners of the kingdom. They left undone many things which they ought to do, and busied themselves in matters which would be better let alone. The duties of the department had far outgrown the machinery which had those duties to perform. The Board of Trade attempted far too much, and there was not sufficient separation between the executive duties connected with shipping and those connected with railways. Shortly before the close of last Session he had given notice of his intention to ask the House of Commons as early as possible to consider whether they should not appoint a select committee to inquire into the duties of the Board of Trade, and into the operation of recent statutes. If that view had the support of gentlemen present, he thought that they should do something to shape public opinion outside. A few steamship owners in the House of Commons could not do much unless they were known to be backed up by a strong outside feeling. He desired to speak with the greatest respect for Sir Charles Adderley and Mr. Stanhope, but yet one could not help remembering that those gentlemen came into their present positions without any special training in regard to the practical details connected with shipping, railways, or machinery, and that

they inherited the mischievous Board of Trade policy made for them by hon. gentlemen on the other side of the House. Whether under the present or the late Government, he thought that the Board of Trade, as a public department, had distinctly "gone off the rails." To a great extent it had driven trade out of the country. It was not possible that all the carrying trade could be done by first-class ships. Second-rate sailing vessels were really necessary to the country's prosperity, and had been displaced to make room for foreign shipping; and that which was true of sailing vessels was becoming more and more true every day of steamers. There was not the slightest reason why it should be so. It was not so much new laws that were wanted as a reorganised Board of Trade; and there would be no great difficulty in procuring that if it were asked for strongly by the public. The present position of matters was this. There was no reasonable supervision, including alike the British shipowner and his foreign competitor, but the British shipowner—and he alone—was overwhelmed with useless annoyances; and the Board of Trade capped these with their theory that disasters were to be prevented by threats of punishment. In regard to the prevention of disasters by punishment for alleged misdemeanour, the shipowner who understood his business and gave personal attention to it was at a disadvantage as compared with the "limited liability man" and the man who did not understand his business. All practical men knew that there was not a railway in the kingdom, and hardly a steamer, that had not some defects, and it was in the careful watching of these defects, or supposed defects, that good management consisted. Accidents, in spite of every precaution, would sometimes happen; and if a vessel was unaccountably lost, it might not be easy for practical engineers and shipowners to get into the witness-box and prove their innocence. Their very carefulness might tell against them. He thought that the Board of Trade had done a great wrong to every practical shipowner and engineer, putting him in a position of personal danger that the ignorant man was not made to share. Shipowners deserved better treatment than that. The practical men who had helped forward the progress of steam shipping during the last quarter of a century were not quasi-criminals. They ought to be allowed the credit of wishing to do right, and should not be discouraged from giving personal attention to their business by such legislation as had of late years been adopted.

Mr. Bruce Bell wished to say a few words on behalf of the Clyde shipbuilders. The Author had written a lucid and complete

summary of the progress of twenty-five years in steam shipping and marine engineering, and the result at which he had arrived with regard to economy of fuel was, he thought, pretty nearly true. Much waste had been prevented, and minuter refinements were now needed, which could only be accomplished by improvements in detail. One point, which no doubt had effected the greatest change, was the introduction of steam of higher pressure; but here the interference of the Board of Trade had, as in many similar cases, hampered improvement. In stating the advantages possessed by the screw propeller, the Author had mentioned that of indifference to rolling; but it possessed one disadvantage in even a greater degree than the paddle, which was its inequalities of action in the case of pitching. This had been remedied to some extent by the application of the governor, but the great defect in governors hitherto in use was that they did not anticipate the racing action of the screw, and only began to act after the engine had actually commenced to race. A most efficient governor which acted by anticipation, was that of Mr. Dunlop, of Port Glasgow, which worked by means of a siphon and small air chamber in the stern of the vessel, the air of which was compressed or expanded according to the depths at which the stern was submerged or free, action being communicated to the throttle-valve accordingly. One of the most important matters to which the Author had called attention was Government interference with the details in construction of boilers and engines, and the vexatious and, in many cases, absurd rules proposed by the Government surveyors. Engineers and shipbuilders on the Clyde took up the matter some years ago, and sent to London a deputation who had an interview with Sir Charles Adderley; but as yet he was not aware that anything had been arranged. He cordially agreed with the suggestion that the Institution should give its aid in endeavouring to put some check upon that unnecessary interference, which had led to no other result than hampering improvement and producing irritation and annoyance. He might instance the case of spring-loaded safety valves, and ask if anything could be more absurd than the continued and determined opposition to their use at sea, where only a moderate pressure was used, when every high pressure locomotive in the kingdom was fitted with nothing else, although pressed to a much greater extent, and subject to much greater liability to accident. When it was considered that, at every roll of the ship in a heavy sea, the angle at which the ship lay relieved the weight of the valves from one-third to one-fourth, it seemed incomprehensible how such opposition could be

made to the discontinuance of so clumsy a system as dead weight loaded valves. It was true that the Clyde shipbuilders persevered in the use of the spring-loaded valves; but they were forced to reduce the load by 10 per cent. over what was allowed for dead weight. It was surely sufficient without exercising such paternal influence, and endeavouring to teach shipbuilders and engineers their business that the surveyors should simply keep to their duties in watching the proper construction and in testing the strength and stability of the work when completed.

Mr. QUELCH was surprised to find that Mr. Bell had fallen into a mistake with regard to the spring safety valve. He had drawn out and made spring safety valves for vessels that had passed under the supervision of the Board of Trade, and it would be seen on reference to the rules and instructions to surveyors, issued by the Board of Trade, that a rule for spring safety valves was given. It was a well-known fact that such valves were now used.

Mr. R. GREAVES desired to say a few words from the point of view of a master mariner. There had, he thought, been an omission in reference to one point. There had been a considerable degree of excitement lately on the question of whether the man at the wheel should be spoken to as a sensible being, having the handle of the rudder in his hand, or whether the rudder itself should be spoken to, or the direction of the ship's head be understood. Some might fail to see the connection, but a sailor would readily understand it. A right-handed screw would send the head of the ship to starboard, and a left-handed screw to port; and if the helm was not moved before the ship had got stern-way, the action of the rudder was not so quick and lively as it otherwise would be. In the event of two ships steaming at the same rate of speed, side by side, the one with a right-handed screw and the other with a left-handed screw, this would arise. If the ship on the right hand side of the other had a left-handed screw by which her head would be cut to port and the other ship on her left had a right-handed screw, the helm in each ship being steadied amidships, these vessels would infallibly collide or clash, because the ship with a right-handed screw being cut to starboard, the collision would be due to the united effect of the screws, each vessel's head being cut round in different ways. If, however, the vessel on the right hand had a right-handed screw which would cut her head to starboard, and the vessel on the left of her had a left-handed screw which would cut her head to port, these two vessels would separate, describe a circle, and again arrive—their paces and all other conditions being equal—in the same positions, relatively to one

another, as at first. In navigating a canal and particularly in passing vessels, this fact became most important. Every screw steam vessel should have a tell-tale indicating how she carried her helm, and a notice on the binnacle that her screw was left-handed or right-handed, and in all cases of collision this point should be brought out. If two vessels were steering the same course, side by side, the one with a left-handed screw and the other with a right-handed screw, their respective helms would be apparently opposed to each other, and the observant spectator would be puzzled, until he discovered that the helm was used, in each ship, to counterbalance the cutting round of the ship's head by her individual screw. He ventured to ask why any ship should have a left-handed screw? There was certainly great danger in it. If he did not know what kind of screw a vessel coming towards him possessed, he could not tell what her master was doing; but if he knew that the ship had a right-handed screw, he could then keep all square. He had lately brought this subject to the attention of the superintendent of a large company in the East Indies, who appeared to be ignorant of its importance. He had seen a ship belonging to that company alongside a rather heavy floating hulk. While she was there she had changed commanders. The commander who went on board had been accustomed to a vessel with a right-handed screw, and no one had told him that his new ship had a left-handed screw. He accordingly proceeded to handle her in the same way as he would have done his last ship, and the result was that in the act of leaving the hulk, while the tide was running with some force, his vessel's head cut round in the opposite direction to that which he intended; she thus did about £500 worth of damage. This was sufficient demonstration that the question was of a practical character. In 1847–8 there was considerable excitement in getting up the Royal Mail Company, and all sorts of inducements were held out to the public to subscribe for shares. He himself joined that company which had a Royal Charter of Incorporation, and a subsidy. At that time a subsidy was looked upon as a great matter, because the industry had yet to be developed, and there was no certainty of success, or probability of an immediate dividend as the trade had to be exploited. All the vessels under the charter were obliged to be so built as to be capable of being rendered serviceable in case of war. Subsidies developed companies, and companies had sometimes unwisely developed competition against themselves, by over-extending their own operations as if they were going to grasp their profits with both hands. He knew such a company in Liver-

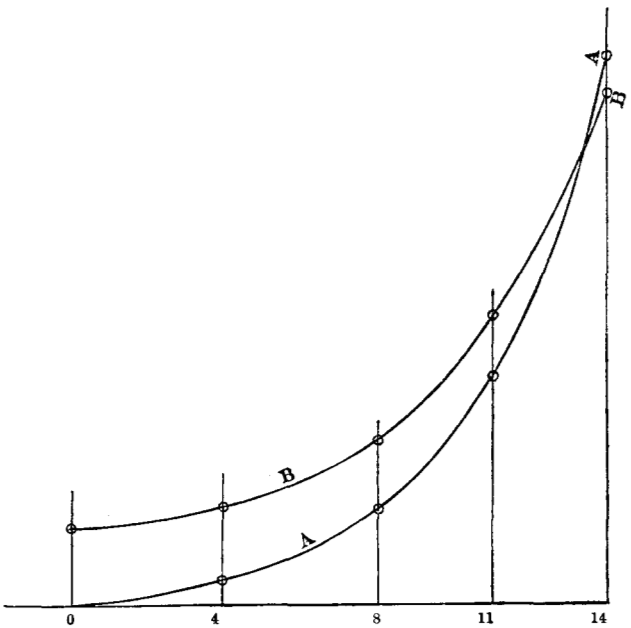
pool at the present moment. There was another reason why vessels had sometimes hung unprofitably upon owners' hands. Great Britain had ceased to develop her colonies as she should have done; had she not failed to develop the national estate there would have been an ample and ever-widening field of employment for vessels which had become somewhat *passé* in the original industries for which they were started. With regard to the interference of the Board of Trade, some persons thought the subject a delicate one, but he saw no delicacy attaching to it. It was a matter that concerned every Englishman, especially every man concerned with a keel. The function of Parliament was not so much to legislate in the first instance, as to inquire how far existing legislation was adequate, and, in the next place, to see how the enormous powers conferred upon the Board of Trade to carry out legislative enactments, were exercised. If the Board of Trade failed in its work, he believed it was in a great measure due to the fact that it resisted an investigation, such as was made periodically in every well-conducted administrative department, and also in all great mercantile houses. If the Marine Department of the Board of Trade was not exercising its powers usefully, it should be put into Commission, and the method of the work should be reformed in the spirit of the law. With reference to what had fallen from Mr. Scott Russell on the subject of the screw, he wished to say that he had been concerned in designing, building, launching, equipping, and sending to sea a small screw steamer, built on the edge of the bush in New Zealand. She was not a bad model, and travelled 12½ or 13 knots under canvas, but was slow under steam, her power being but small. During the time he was in the vessel it constantly occurred to him that the pitch and diameter of the screw ought especially to be studied with regard to the form or run of the vessel. It would be an act of folly to bore into a wood of long loose fibre with the same shaped auger as would be used in boring into wood as dense as teak or oak. It therefore appeared to him that what was wanted was a screw that would get the greatest resistance on the water just where the water would allow it to exercise its full power. There were two threads of water, one on either side of the vessel, and it was into those threads that the screw had to bore; now to bore effectually there must of necessity be a good set. He fully appreciated what Mr. Scott Russell had said upon the subject. If greater attention were paid to jacketing cylinders and casing boilers, there would be much greater economy. He had heard, however, that the jacketing of cylinders was really

a sham—that it was not done thoroughly and properly, and therefore no economy was derived from it.

Mr. FROUDE said there was one point to which he desired to call special attention, namely, the importance to a body of engineers of contemplating the questions raised in the present discussion, from an engineer's and not solely from a shipowner's point of view. To a shipowner the main question was, whether his ship would perform a voyage with a diminished consumption of coal for the same tonnage. The engineer, on the other hand, would not look at the thing in the lump, but would rather separate the whole question of propulsion into the different elements on which it depended. He could best emphasise what he had to say on the subject by stating that, in virtue of the experiments which he was conducting for the Admiralty, and which had given decisive results, enabling the true resistance of ships at various speeds to be ascertained, it was known that of the total HP. expended in propelling a ship, the useful expenditure of power—that which was simply due to the delivery of so much force at so much speed—did not in general amount to more than 37 or 40 per cent. When it was considered that such an enormous loss was taking place, it might well be desired to look into all the elements on which the expenditure depended, in order to see at what point improvements might be effected. He wished to refer to one circumstance in reference to the usual mode of estimating the merits of a ship, which he thought had been conducive to a great deal of misconception, and had retarded or misdirected investigation, namely, the way of expressing results attained in HP. simply, and not in propulsive force. He could best illustrate his meaning by describing what had happened in the analysis of certain interesting results brought forward by Mr. Denny, of Dumbarton. Mr. Denny had not been content with the usual mode of trial of his ships at what was called full speed, and half-boiler power, or half speed, but he decided that he would get a regular progression, from the highest powers he could deliver to the lowest, and correlate them with the speed of the ship. In that way a series of interesting results was obtained, and expressed in the form of a diagram such as that marked A A. The base line represented units of speed; the ordinate was HP., and the curve thus produced went through the zero of HP. at the zero of speed in virtue of the speed-factor in indicated HP.; but when the matter was separated into its constituent elements, a totally unexpected, but most instructive result was obtained. Dividing out from HP. the speed factor, propulsive force was obtained, or the equivalent. It was usual to represent

the work done by an engine by the product of the pressure on and the speed of the piston; but it might be described equally well on the supposition that no friction existed, by the product of the virtual speed of the screw and the force delivered by the screw. Now using the force factors thus deduced from Mr. Denny's experiments as ordinates, at each speed, a curve was obtained of the kind shown, in which the force ordinate refused to come to zero at the speed zero. The lowest speed was about 3 or

FIG. 1.



A A. Curve of Indicated HP.
B B. Force curve. Ordinates proportional to mean pressure on piston.

4 knots; and a fair curve drawn through the force ordinates given by the succession of speeds, instead of being a curve running down to zero, was a curve that terminated on an ordinate about $\frac{1}{7}$ of the maximum force ordinate, delivered at the highest speed. That, when looked into, represented the dead friction of the engine, the force required simply to turn the engine round when unloaded. A variety of ships was tried in that way, and all the curves, when analysed in the same manner, yielded about the same result. There were among them two sister ships on the same lines, and with as nearly as possible the same engines, and when the HP. curves

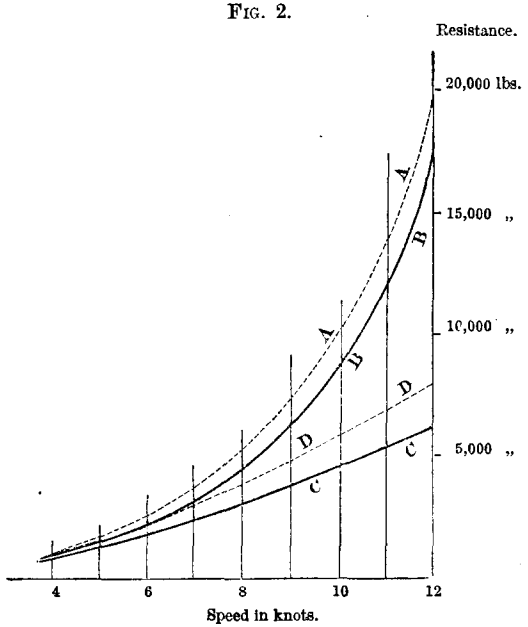
were produced, the result was very heterogeneous and incomprehensible, the curves intersecting each other, so that it could not be seen what their relation was; but when the alteration he had advocated was made, the force curves were precisely or almost parallel, showing a little excess of constant friction in the engines of one ship over those of the other, and giving a completely intelligible result. Those were two reasons why he thought it important to divide the subject into its elements. It would at once be seen that $\frac{1}{7}$ of the maximum force exerted by the engines was always going away in this particular kind of friction, and it was as great at the lowest speed as at the highest. That was a very heavy tax on engines which were fitted to work at a high power, but which were habitually worked at a moderate power. There was also another large element of friction due to the work delivered by the stress of the steam on the working parts. Take, for instance, the crank pins of a large marine engine. He had especially in his mind a ship, the indicator diagrams of which he had analysed. The crank pin was 22 inches in length, and about 22 inches in diameter; and it came out that when the engine was working at the highest power, and at its greatest speed, the work delivered in the shape of friction on the surface of the crank pin (assuming the co-efficient of friction to be $\frac{1}{15}$, which however, was possibly too high), was almost equivalent to a delivery of heat at the rate at which heat was delivered to the internal surface of a fire-box of a locomotive. The heat delivered at that rate had to be radiated away or got rid of in some manner by the crank arms and connecting rod brasses, but there was a great deal of heating and trouble with it. Then there were the packings of the piston and the like—all elements of friction, and each deserving separate investigation and study in order to see whether it was possible in any manner to reduce the loss. Again, there was another element introduced by a function of the propulsive force—the adventitious resistance produced in a ship's motion by the action of the screw propeller, where it was actually working. The screw propeller, working under the stern of the ship, pushed at the water, and propelled the ship; but in pushing at the water it made the water press less forcibly against the stern of the ship, and in consequence it produced a definite increment of resistance. By his Admiralty experiments he knew that in a great many ships that augmentation of resistance was as much as 50 per cent. He had no doubt that the common run of steamers had an adventitious or augmented resistance equal to 50 per cent. of their natural resistance, created by the very instrument that propelled them. It

might be interesting to point out the manner in which the fact had been crucially tested in the experiments to which he had alluded. The experiments were performed in a tank 300 feet long, with a working run of 180 feet, 10 feet deep, and 36 feet wide at the top, so that it was above all suspicion as to waves set up by the motion of the body. Just above the surface of the water was suspended a railway, with a 3-feet 3-inches gauge, and on that railway ran a truck carrying a very delicate dynamometer which pulled the vessel along at any assigned speed at which the truck was driven by a steam engine with a delicate governor. The model was held simply by the dynamometer, and by two delicate knee-jointed frames called guiders, so that the force measured was the pure, simple, propulsive force employed in driving the model. Everything was recorded on a travelling sheet of paper in the usual way. The speed was registered, as well as administered, and thus an exact record was obtained of the resistance of the model in terms of the speed at which it was run. It was run at a great variety of speeds, and a curve of resistance was obtained. The base line represented speeds, and the ordinates the resistances at those speeds. So much as regarded the determination of the model's natural resistance. Then as regarded the action of the screw, there was also provided the means of coupling up behind the dynamometer truck another truck, in which there was a separate apparatus—a suspended dynamometrical frame, from which there was hung, by a delicate bracket apparatus, a horizontal screw shaft, at an adjustable depth below the surface, protruding forward in front of the truck, and carrying a screw which was speeded to any speed, by a belt driven from the wheels of the truck. If that pair of trucks was run without a model, the screw could be urged at such a speed that it would exactly cut the water edgeways, without producing propulsive force or reaction, or any other speed so as to produce any thrust which it was capable of exerting. A diagram was made showing the pull of the screw on the dynamomitive screw frame, and also a diagram of the force administered by the belt, to make the screw turn round. This was a test to ascertain whether the screw was working neutrally, or whether it was in effect stripping the thread in the fluid nut and exerting propulsive force. Having set the screw to cut the water exactly, so that it simply went edgeways through it, the model was then coupled up in front of it, and having previously ascertained the resistance of the model at the given speed, it was seen what happened when the screw was brought into such close juxtaposition with the model, not touching it, but so centrally placed, and at such a level, as that it would be

at the place it would occupy if it were propelling the model. The screw in that position was still driven with exactly the same speed as that at which it had previously been merely cutting the water, without exerting any propulsive force at all when there was no model in front of it and the water was undisturbed. The introduction of the model at once produced two results. The screw was now exerting large propulsive force, equal to about 20 per cent. of the previous resistance of the model, and the model itself exhibited a considerably increased resistance: instead of pulling only about 3 lbs. at the tow rope, it pulled nearly 3½ lbs. Repeating the same experiment, and speeding the screw higher and higher, there was obtained a greater and greater propulsive force delivered by the screw, and at the same time a greater and greater augmentation of the model's resistance; and there came at last a point at which the screw's growing thrust had overtaken the augmented resistance of the model. There was then a state of things in which if the screw had been attached to the model, as if forming part of the complete system of propulsive machinery of the model, it would be running at such a speed as precisely to drive the model at her existing speed. Then the augmentation of the model's resistance varied somewhat according to various circumstances which had to be taken into account, the fineness of the run of the model, the thickness of the stern post, whether there was a false stern post behind the screw or not—all those things had to be taken into account, but the result was that, assuming the ship to have an ordinary fineness of run, there was an augmentation of resistance of from 40 to 50 per cent. He did not wish it to be supposed that the models were mere toys; they were boats of from 10 to 25 feet in length; they were manufactured exactly to lines and loaded exactly to their proper displacement, so that it was possible to compare the result of their resistance with the resistance of the ships they resembled and deduce what the latter would be. By some of those experiments it had been ascertained that there was the extraordinary waste of power to which he had referred, 37 per cent. being all that was realised. He might be permitted to mention a reason why he confidently stated that the results obtained by the experiments were true. Some years ago he had to conduct for the Committee on Designs a series of dynamometric experiments with an old corvette, which had the reputation of being a good sailer and steamed fairly. The ship was tried at her normal immersion, her normal trim, and varieties of trim by the head and stern; she was also tried at two other separate immersions, light and very light, so that the trial made with that ship was virtually

a trial with a great number of ships. He wished to show how the actual result thus obtained with the ship corresponded with that indicated by her model. The curve of resistance for the ship, as obtained by the dynamometer, was a curve like the curve AA shown on the diagram. The curve of resistance obtained by the experiments with the model is shown by the curve BB. The model was tried with all the changes of trim and of immersion that the ship had gone through, and it was found, in every instance, that the

FIG. 2.



A A, curve of ship's actual resistance.
B B, curve deduced from model for ship if with skin clean painted.
C C, curve of ship's skin friction if with surface clean painted.
D D, curve of ship's skin friction if with one-fourth part coated with calico over the paint.

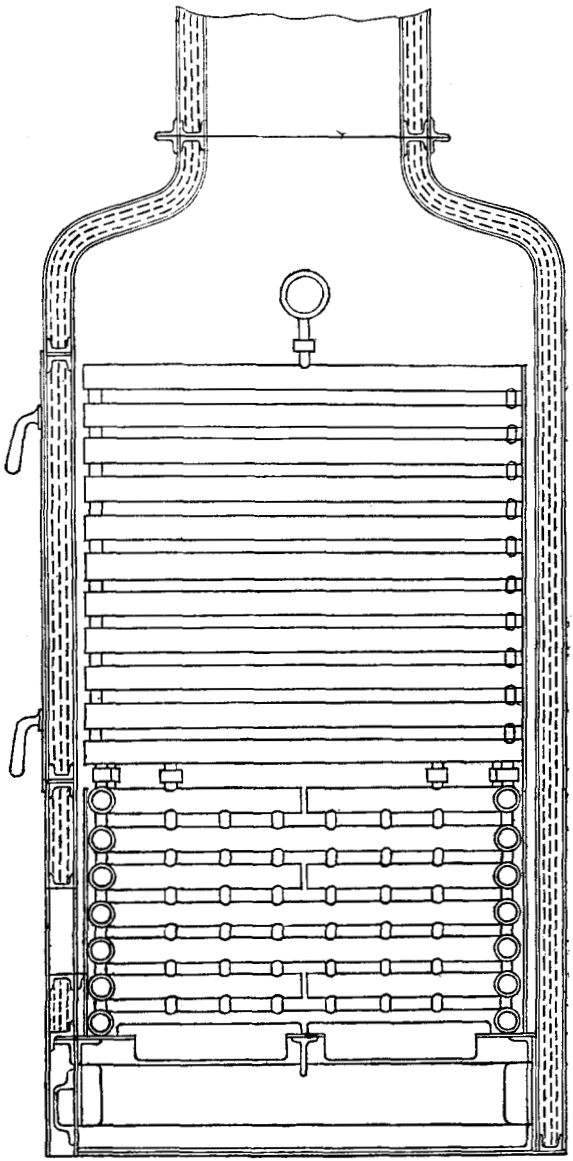
resistances exhibited by the ship with varied trim and of immersion were reproduced, under the same variations of trim and immersion with the model, almost exactly, but with fairer curves. The dynamometrical results obtained with the ship, though slightly irregular, because it was difficult to get the exact speeds, yielded fair average curves possessing characteristic differences; for instance, they showed that at a high speed the ship did better when trimmed by the stern, and that at a low speed she did better than when trimmed by the head. All those characteristic results were reproduced by the model. The curves, though much alike,

implied by their slight difference that, judging by the model, the ship ought to have made rather less resistance than she did, and *primâ facie*, it might be thought that that was evidence of some incorrectness in the indications given by the model. The interpretation of the descrepancy, however, was the following: a very large proportion of the total resistance, whether of ship or model, consists of surface friction, and is measurable in each case by the area of immersed skin, the quality of its surface, and the speed; and an extensive series of experiments had therefore been conducted to determine the co-efficients of resistance for surfaces of various qualities. This series, however, did not include old rough copper, such as that of the ship. The ship's resistance was, in the first instance, calculated on the supposition that the quality of the surface was equivalent to that of smooth paint, and it was the resistance thus calculated that fell short of the truth. It was probable that the rough copper had a more resistent surface; and at all events the difference would have been exactly obliterated if it had been assumed that a strip of ordinary unbleached calico had covered one-fourth part of the surface of the paint. On these grounds he ventured to state that the experiments with models gave a correct measure of ship's resistance, and that in virtue of that measure it was possible to determine how much nett HP. a given ship should require at a given speed, and from numerous comparisons between this and the actual power required, to state that, in a general way, an amount of only from 37 to 40 per cent. of work put into the engine of a screw ship was actually realised. The moral which he desired to draw was the great importance of separating, as far as possible, the expenditure of power into its constituent elements. The Admiralty had instructed him to work out a design for a dynamometer which might be substituted for the screw at the end of a screw shaft to measure exactly the power given out at that point by the engine; and he had succeeded in contriving one somewhat of the nature of a turbine, which, tested by a couple of good-sized models of different dimensions, justified him in the belief that a circular drum or casing about 5 feet 6 inches in diameter and 2 feet 6 inches in length along the screw shaft might contain a turbine, which would take up 3,000 HP. when rotated at about 90 revolutions. He was expecting an order from the Admiralty to get such an instrument made, and in that case the apparatus would be applied and made to record the actual power delivered at the screw end of the shaft by the working engine.

Mr. Loftus Perkins said that engines of his design were now working with steam at from 350 to 400 lbs. pressure in tubular

boilers (Fig. 3), which appeared to have a long life.[1] They were

FIG. 3.



[1] *Vide* Institution of Mechanical Engineers, Proceedings, 1877, p. 117.

worked with distilled drinking water or rain water. The samples exhibited were those which the Admiralty Boiler Committee had cut out of boilers worked in that manner for eighteen years; it would be seen that they had not deteriorated. It had been stated by the Author of the Paper that jacketing was of no use; but it had been found that the greater the expansion the more necessary it was to provide the cylinders with jackets. Engines with low-pressure cylinders would stand the jacketing with high-pressure steam, 450°, without injury, and the economy was increased by keeping it at that temperature. In working with those high temperatures it had been found necessary to get rid of grease and oil, and a metal had been discovered which required no lubrication. In the course of six months a number of such engines would be at work, so that their capabilities at sea could be ascertained. It had been objected that rough sea usage would injure them, but he did not believe that long voyages would give any trouble. The most troublesome voyages to marine engines were the short ones, and the engines that suffered most were those that were worked on rivers. The expense of keeping in order the engines of passenger ships on the Tyne was equal to the whole remaining expense of maintenance. A boiler worked at sea was fired perhaps once in thirty or forty days, and did not suffer from expansion and contraction. The boilers that suffered most were those fired up twice or three times a day.

Mr. JOHN DIXON regretted that the Author had but little hope of future economy in the consumption of fuel. It was true that the consumption had been reduced from 6 to 4½, 3, 2½, and (in some exceptional cases) to 2 lbs. per indicated HP. per hour. But heat and mechanical force were synonymous terms, and it was well known that 1 lb. of coal ought to produce much more power than was realised from it. Theoretically 1 HP. ought to be produced with ½ lb. of coal, and though that result might not be attained, he thought the consumption might be reduced in a material degree. He did not agree with the Author in thinking that any further saving must lie in the reduction of wages. Engineering talent and the extension of the naval service had produced an increased demand for luxuries, and hence wages must inevitably continue to advance. Wages, however, might be materially economised by the use of steam for a great part of the somewhat laborious work on shipboard. The Americans had gone far ahead in that direction by the use of donkey engines and other appliances for economising labour. He could see no reason why steam should not be applied in

steering, and also in the stoke-hole, in the trimming of the coal and the like. With regard to the attacks that had been made upon the Board of Trade, he thought that those who attacked any public department ought to suggest a remedy for the evils of which they complained. He also thought that a public department like the Board of Trade might do something towards establishing new standards that would be useful to engineers. How many members present could tell what a nominal horse-power was? He was sure he could not. The Author had expressed regret that the steam trade of England had not been very remunerative; but seeing the extent to which the leading firms had increased their steam shipping, and the extent to which the steam shipping of England had been augmented during the last twenty years, it was surely taxing the credulity of the Institution to say that the trade had been a bad one.

Captain Bedford Pim, R.N., M.P., said the mercantile marine of the country now numbered some twenty-five thousand ships, of which not five thousand were steamers, showing, he thought, that the Author was mistaken in stating that steamers were entirely superseding sailing ships. Having been a great many years at sea, and having seen a great deal of the mercantile marine and the navy, he had no hesitation in saying that the mercantile marine was even of more importance to the country than the Navy itself. Two-thirds of the food of the country were imported from abroad; in fact, an addition of 40,000 tons of shipping was required every year, due alone to the necessity of supplying the new mouths, which increased at the rate of two hundred and sixty thousand per annum, the metropolitan area alone adding to the population about thirty-five thousand souls a year; hence the importance of seeing that the mercantile marine was efficient, not only in ships and engines, but in men, most of whom he was sorry to say were foreigners. He held in his hand a model of the long steamship of the present day, but only nine times her beam for length, whereas ten and eleven times were common. It must be evident to any one who had been at sea what would be the fate of such a vessel if an accident happened to her machinery, and she fell into the trough of a sea in a gale of wind. He maintained that she must inevitably go to the bottom. He also exhibited a model of a ship of the same tonnage, but of proper proportions, four times her beam for length. The long vessel was, no doubt, a fine one for the shipbuilder and the naval architect, but it was a bad one for the shipowner, requiring one-third more iron and materials and heavier scantling. It required also more repairs

than the other, going through the waves, instead of over them. A glance at the long narrow model would prove this, for a ship must seek her displacement, and if her ends rested on two waves the sea in bad weather would break inboard on both sides, both forward and aft at the same time. If the ship was waterborne by her middle the strain was excessive, and the sea broke inboard amidships with great force. Under any circumstances the long narrow vessel was unsatisfactory, the original cost was higher, she rolled more, she made worse weather, the cost of repairs was more, she was a bad sea-boat, and if an accident happened to the screw in a heavy seaway she was helpless. From a list of wrecks during the present year it appeared that about two hundred ships highly classed were missing. When such a ship went to sea most persons would exclaim, "What a magnificent ship she is"; but at sea, in a heavy gale, a slight accident would render her unmanageable, and then no sailor could keep her from going to the bottom. Formerly, when there was a collision at sea, the carpenter could repair the damage, and a brush of paint did the rest; but it was now far otherwise. With fewer ships than twenty-five years ago the number of collisions was greater. One reason for this was the inordinate length and narrowness of our ships. He would like to point out to the meeting that the power of the rudder was in inverse proportion to the length of the ship, and that when a captain saw another vessel approaching dangerously close he gave orders to stop, without reflecting that the rudder ceased to act almost as soon as the screw stopped. He did not care to speak on the scientific aspect of the question, but merely as a sailor, and he regretted deeply to see the rubbish now launched, both as to design and material. He remembered being in the Arctic regions, in company with the old "True Love," which was built in 1764, and was on the Register at the present moment, being fit to go to sea and encounter any weather; while several whalers were crushed she withstood the pressure of the ice. The Author had stated that until the advent of steam there had been no improvement in merchant shipping from the time of Julius Cæsar. A sailing vessel at that time had only one huge mast and one sail, like the vessel in which St. Paul was shipwrecked, and which was "undergirded"; but it was rather incongruous to compare such a ship with a sailing vessel of modern times. Besides that, it was not until thirteen hundred years after the time of Julius Cæsar that even rudders were invented. With regard to the speed of sailing ships, eighty years ago a frigate went from Quebec to Portsmouth in eleven and a half days. He could not

but express his regret that naval architects were not to be found who could really design a ship somewhat better than that of the model which he had exhibited.

Mr. PHIPPS asked Mr. Froude to explain one or two points with reference to his dynamometer. The first was as to the growing power as the water kept travelling from one cell to another out of the turbine. How would Mr. Froude manage if it were required to maintain a constant force upon the recording spring for some five or ten minutes' observation? It appeared to him that unless the pressure were modified by shutting off the water by the shutters between the turbine and the fixed part, it must be undergoing a constantly increasing "potential." He also wished to ask whether there was not a great deal of leakage in the lateral division between the moving turbine and the fixed part, there being merely a mechanical fit of the two edges; and, further, whether there was not a considerable centrifugal pump-like action when the apparatus was set to revolve in the water around it.

Mr. FROUDE replied that the growth of resistance was all completed in the first two or three revolutions. When the thing was begun to be turned at a stated speed it made more and more resistance, until the total force employed in driving made up a force equal to the frictional resistance of the water; so that it was only for a second or two that the force remained a growing one. As to the disruptive action of the separating forces of the two parts, each complete turbine consisted of a pair united back to back, so that they pushed merely against opposite sides of one case. There was one large case embracing the turbines, and if it were strong enough no difficulty would happen. With regard to the rotation of the water, that was all inside the turbine; it would not happen outside; the strain on two casings would be simply measured by a lever brought to a spring and registered in the usual way.

Mr. PHIPPS said he had given a good deal of attention to the measurement of the resistance of vessels and the great loss of power by the presence of the screw too near the ship. In a Paper read by him in the year 1864,[1] he had referred to that matter, and said that a ship and screw ought to be considered as one compound machine; that the minus resistance occasioned by the screw pushing that water away which ought to be helping the ship behind, was one great source of the loss of power. On that

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxiii.

point Mr. Froude had, he believed, made many experiments, putting the screw on the shaft at a considerable distance from the stern, and obtaining superior results. The Paper to which he had alluded was mainly directed to an attempt to ascertain what was really the friction of the skin-resistance of ships. Up to that time it had been a common doctrine that resistances on ships' surfaces and in pipes were not comparable; but he believed he succeeded in showing that, while following the same general law, the co-efficient for friction was greater in the pipe than on the surface of a ship, when the conditions of smoothness and nominal velocity were the same in each. In the Paper now under discussion, the utility of the indicator diagram had been, as he thought, unnecessarily depreciated. He was of opinion that the comparative merits of two sets of engines could be sufficiently well determined by a careful examination of the indicator diagrams, coupled with the consumption of coal, both taken over a sufficient length of time, without any reference to the dynamometer. The difference of power exhibited by this instrument and by the indicator could only be that due to the friction of the shaft bearings and other moving parts, which with engines of average good construction, in good working order, would not, he thought, amount to any large proportion of the whole power; and it should also be borne in mind that the considerable amount of friction occasioned by the thrust of the screw shaft against its bearings was not measured at all by the dynamometer. He was inclined to the opinion that the greatest possible difference of friction would often exist between trials of the engines with the vessel at rest, moored in a dock, and when in actual motion at sea, owing to the working of the vessel, and consequent bending of the propeller shaft, leading probably to its frequent fracture. With regard to the interference of the Board of Trade and other public bodies, he did not think it was any disadvantage to have certain rules laid down for the guidance of those concerned. For instance, the rule of 5 tons to the inch laid down by the Board of Trade for railway girders was a useful one, putting engineers more on a level, and preventing their employers from complaining about unnecessary weight of the parts. The effect might be to a certain extent to stop inventions; but was not that often a wholesome one? In regard to the introduction of steel, for instance, it would not have been an advantage to have had it used for ships too soon. Mr. Barnaby came to the conclusion that it could not be trusted, although now he believed he was building a ship of that material, and it was well known that if holes were punched in certain kinds of steel the whole plate

was rendered useless. Was it not a great advantage that Government had not adopted steel until after more experience had been gained through the experiments of Dr. Siemens and others? But for the delay, the use of steel might have been retarded for many years.

Mr. J. R. RAVENHILL wished to draw attention to the increase of tonnage in the mercantile navy registered in London in 1876 as belonging to the British empire. In 1854 there were 326,452 tons of steamships registered; and in 1876 the figures had increased to 3,293,487 tons. At the latter date there was a total of 584,106 nominal HP. During the past five years there had been an increase of 158,000 HP. He regretted the Author had not given further details as to the great changes that had taken place during the past twenty-five years. The iron vessel twenty-five years ago was an accepted fact, and the screw propeller had, some time before that, proved its vast superiority over the paddle-wheel. From the time when H.M.F. "Niger" was fitted with a screw, and H.M.F. "Basilisk" was fitted with paddle-wheels, and they were lashed stern to stern, and started in opposite directions, the screw propeller established its superiority, and was accepted by engineers as the future mode of propulsion, except in cases where, from want of draught of water, or other necessities, the paddle-wheels were still adhered to. If the vessel to which he had alluded had been fitted with feathering wheels, the advantage of the screw propeller would not have been quite so great. He also wished to direct attention to another series of Government experiments, in the early days of iron vessels, on board the "Minx," "Teazer," "Rifleman," and "Sharpshooter." The "Minx" and "Teazer" were sister ships of about half the tonnage of the "Rifleman" and "Sharpshooter." One of each of the pair of vessels was of wood, and the other of iron; and the same lines were adopted in each case as far as the use of wood would allow. The superiority of iron as a material for shipbuilding was clearly demonstrated. The lines that were finer forward no doubt assisted in the result, but greater benefit was found from the fine lines aft which the iron stern post enabled the builder to adopt. The result was that the iron vessel with half the power went the same speed as the wooden vessel with double the power. One of the largest subsidised companies built an iron vessel in 1843; in 1844 they ordered four vessels of 1,800 tons each and 450 HP.; and from that time to the present they had only ordered three wooden ships. The Admiralty also at that time showed their confidence in iron as a material for large

ships, for they laid down the screw frigates "Vulcan," "Megæra," "Termagant" and "Simoon"; and although, before they were completed, experiments had shown that iron was not suitable for vessels of war, they were completed as transports, and afterwards did good service. There could be no doubt as to the advantages of the compound engine. He had read a Paper touching on the subject in August last, at a meeting of the Institution of Naval Architects held at Glasgow, in which he had given figures showing that the commercial advantages obtained on every ton of coal expended in the use of compound engines under the present system, over the ordinary jet-condenser engine working with 20 or 30 lbs. pressure on the boilers, varied from 126·2 per cent. to 54·8 per cent. The Author had stated that there was now less incentive to further economy than there once was with regard to the consumption of coal, and that shipowners were turning their attention to other items. There he joined issue with him. Coal was still a point to which the owner must look, for reduction in the consumption of coal meant decrease of labour, not only in trimming the coal from the bunkers to the stoke-hole, but also in feeding the fires with it. The remarks of Mr. Froude were most valuable, and had led up to a point on which he believed he could give some interesting information. Mr. Froude had spoken of the enormous loss by friction in large marine engines. If that friction could be reduced, coal would be saved. During the last few months he had examined a plan of bearing which had been successfully used in the crank pin brasses of the White Star packets running between Liverpool and New York. It was, he believed, an American patent; it consisted of an ordinary pair of brasses studded with pegs of a patent white metal, somewhat similar to that in use in this country. The brasses as originally fitted had those pegs of considerable diameter. The pegs had, however, been increased in number, and wherever a hole could be drilled between the original ones smaller pegs of white metal had been introduced. The brasses were in the first instance bored out in a lathe to a smooth surface. Experience had shown that the white metal expanded somewhat more freely than the brass. The ends of the pegs thus projected a trifle above the brass. On looking at the brass he could not help being struck with the fact, that when once the bearing became properly lubricated, any oil that got amongst the pegs could hardly get out. It was well known that with a jump on the brasses the oil would go, and it was difficult, with a large pair of engines, especially when they were first started, to get them to go without

some jump. Those bearings had stood the test of many months: they were composed of pegs of white metal, the interstices being filled with oil. Formerly a set of brasses used to be worn out between Liverpool and New York, and they had been a source of much trouble on each voyage, but now they ran continuously without any trouble at all. The same kind of surface was also being used for guides, and he could see no reason why it should not be used for the main bearings. If that were done a vast stride would be taken towards the extinction of hot bearings, and towards the further reduction of fuel. Indicator diagrams were no doubt interesting to engineers and to scientific men. At the same time the shipowner only looked at the matter in a broad view, as to how much cargo in cubic contents, or how much dead weight could be carried over a given distance at a certain speed for a certain weight of coal. That weight had to him a known money value. It was a commercial diagram of which he thought more than any indicator diagrams received from the engine-room. Allusion had been made to the "Great Britain." She was a wonderful ship; she had been greatly altered, no doubt, from the time when she passed the winter in 1844 in Dundrum Bay before her great success in the Australian trade; but she was certainly most regular in the performance of her voyages. Her speed was about $8\frac{3}{4}$ knots, and he well remembered her coming into dock at Liverpool, and whilst standing on the quay alongside the men saying to him, "She is so punctual that we sets our chronometers by her." With reference to auxiliary ships, the speed of the fleet of Messrs. Wigram had increased about $1\frac{1}{4}$ knot beyond this, say to about 10 knots per hour. Such hitherto had been the service to Australia. Within the last few weeks a ship had been placed on the Pacific line the average speed of which all the way to Melbourne had been 12·96 knots per hour, one of the greatest feats in steam navigation. The Author had drawn attention to the expense of subsidies. There could be no doubt that subsidised companies had rendered good service to the country; and he believed it was the boast of the Peninsular and Oriental Company that, although their mail bags had on one or two occasions been submerged, the mails had never been totally lost. The companies had been trammelled by the ships being fitted to carry guns—both the Peninsular and Oriental Company and the Royal Mail Company. The Cunard Company might have had a somewhat easier time. With all their faults, those companies had greatly assisted the allies during the Crimean War, and had done good service during the Indian Mutiny. There was one point connected with the subsidies

with which he had been greatly struck. He held in his hand an abstract of tenders offered for the conveyance of the West India mails, dated 28th January, 1874, printed by order of the House of Commons, and amongst the names of the parties who tendered on that occasion he found that of Mr. Alfred Holt. No doubt the Author would explain his reasons for having so suddenly changed his mind. The supervision of the Board of Trade had, no doubt, in the first instance, been established for the purpose of survey. All the earlier Reports tended to show that intention, but latterly it had to some extent been departed from. Connected for the last few months with the Wreck Commissioners, it had been his lot to sit between the Board of Trade, the shipowner, the engineer, and the public, and he had listened with great pain to the remarks made against the Board of Trade. If any change was to be effected, it would not be brought about by hard words; and it should be remembered that the officers of the Board of Trade had frequently very onerous duties to perform.

The Author had made an allusion to a little book from which he should like to make a quotation. A great deal of unpleasantness had arisen as between some parties connected with the engineering world and the Board of Trade. Up to a recent period engineers made their own boilers and never went near the Board of Trade —everybody did what he thought right—then the Board of Trade officials said that they did not agree. It was suggested that the thing should be taken into consideration. It was represented to the Board of Trade that boilers well constructed, well designed, and made of good material, should have an advantage in the matter of working pressure over boilers inferior in any of the above respects, as unless this is done, the superior boiler is placed at a disadvantage, and good workmanship and material will be discouraged. The Board of Trade surveyors have endeavoured for some time to take all these points into consideration in fixing pressure, and for this purpose the following Rules were prepared, and at the request of engineering firms subsequently circulated."[1] He ventured to suggest for the serious consideration of the Board of Trade, and with a view of throwing oil upon the troubled waters, that when a great change was proposed, such as had recently taken place by the introduction of high-pressure steam, they should ask the manufacturers to send three or four selected representatives to consult with three or four officials from the

[1] Instructions to Surveyors of Ships. Clause 90. Cylindrical Boilers.

Board, adding two or three gentlemen who were acquainted with marine matters. Such a conference would thresh the subject well out, and a small committee taken from amongst them might be formed to frame rules. The manufacturer would then know who framed the rules. It was often said at the present time, "The rules may be all very well, but we do not know who framed them. We are told to do this, that, and the other, and we cannot help ourselves." The Author had alluded to surveys connected with railways as compared with surveys connected with steamers. He did not think that a locomotive ever ran twelve hours without stopping; and certainly none of its parts were as massive, as heavy, or as liable to be deranged as the heavier parts of a steamer. But what did the Board of Trade say? "You may do as you like with your locomotives; we will take care of your permanent way." The walk of an ex-railway official from Bristol to Exeter would long be remembered. But what about the other permanent way? The Board of Trade never determined when a ship was to go to sea and when she was not to go to sea; and they were wise in not doing so, otherwise they would have been inundated by letters from people saying, "Why did you subject us to the horrible inconvenience we suffered the night before last in crossing the Channel?" In the case of a ship leaving for a round voyage the survey of her machinery should be most complete; but while he would argue in the strongest manner for a survey, survey should not stay progress. He had during the last few months seen ships and machinery, such as he had had no idea were in existence, trading round our coasts. They were a disgrace to the present day, but unfortunately they could come under no survey. Owing to certain clauses introduced into the Merchant Shipping Act, they were exempted altogether from surveys of the Board of Trade, and to a great extent of Lloyd's. With regard to the progress of steam navigation, one of the greatest strides that had been taken for a long time was the introduction by the London, Chatham, and Dover railway of the steel mail packets, "Samphire," "Maid of Kent," "Scud," "Petrel," and "Foam," of 340 tons and 160 HP., and 503 tons and 240 HP., when they commenced their Channel service in the year 1861. They had stood the test well. The hulls were still in perfect order, and the result ought to give confidence in the introduction of steel in vessels. He had lately seen in some steel works a forging for a connecting shaft with a cheese coupling, which had proved a complete success. Three years ago one of the leading steel houses attempted a

similar thing, and, after three failures, had been obliged to give it up. No allusion had been made to the patent metal of Sir Joseph Whitworth. That metal, like many other things, came in at a timely moment when engineers were troubled with the cutting that was taking place in the high-pressure cylinders of compound engines. As far as experience had hitherto gone with that metal, it appeared to be a decided success. Sir Joseph Whitworth had also introduced hollow propeller shafting of the same metal with a considerable saving in weight in the total length of shafting on board large screw steamers; in fact many tons were saved, and that, of course, meant a saving of coal, because there was less weight to be carried. No reference had been made to the introduction of the twin screw; and he thought that the history of the last twenty-five years would not be complete without some allusion to it. It might not have been used much in the commercial marine; but its advantages were often so great that it was worth passing notice. He had seen a vessel built and fitted with a single propeller tried against a sister ship fitted with a twin screw. In the one case a very small disk area of propeller was obtained in proportion to the midship section of the vessel, and in the other case a large disk area. The vessel with the twin screw beat her sister ship by more than 1¼ knot an hour. What was wanted in these high-pressure days was a new form of boiler, with all its parts accessible for the purposes of repair and examination. He had seen several cases in which serious accidents had taken place, and no one had any idea that the iron had been reduced in thickness from oxidation so materially as it was. The reduction took place in the water spaces round the bottom and sides of the fire-box, which it was very difficult to inspect. It had been recently stated that a new mail service was to be commenced on the 1st of January between Liverpool and New York, to be carried on by the White Star, Inman, and Cunard Companies in concert. They were about to carry mails three times a week, and he was much mistaken if the service would not be carried out at the speed exceeding 15 knots. The White Star Company had, during the last four years, led the way with reference to the Transatlantic service, but other vessels had been built which were fast treading on their heels, and he was not sure that the Inman Company had not made one shorter passage than the White Star. With such a result the Holyhead service, which had been for so many years pre-eminent, would be cast into the shade. He observed a drawing of the safety valve of the steamship "Sidonia." The boiler explosion on board this vessel had

been the subject of an inquiry before the Wreck Commissioners in July last, at Edinburgh, and he trusted that that form of valve, or rather that application of the weights, would be abandoned. There was a Salter's spring balance at the end of the lever. The Board of Trade took exception to it, believing that if the spring gave way there might be trouble; that the lever would fly up and the steam escape. Means were then contrived by which a weight could be lowered, and although he believed the alteration was not considered entirely satisfactory it was accepted. The weight was fastened up in the vessel by means of chains and padlock. The padlock was under the charge of the captain and chief engineer, as were all padlocks connected with safety nozzles on board ship, but it was proved to the satisfaction of the Court that the engineer had not only fastened down the safety valve on the superheater, but had lowered the weight on to the lever to bottle up the steam, so that the boiler was carrying, as nearly as possible, double the amount of pressure that it ought to have carried.

Admiral SELWYN observed that the question under discussion, at all times an interesting one to Englishmen, was doubly so now, since the support of the nation depended much more largely than formerly on its commerce. Our staple industries and work of every kind had found rivals who could not be met in any other way than by continued progress, and he confessed to a little disappointment with the Paper to find that, while speaking enthusiastically of former progress, the Author had put the small limit of 25 per cent. to the progress of the next twenty years. He should have occasion to speak of a great improvement which had more than quadrupled all that the Author hoped might be obtained in twenty years, but of which he did not appear to have taken any notice. An advance had been made from 600 to 6,000-ton steamers; from 20 to 80 lbs. pressure; from 4 lbs. of coal per indicated HP. per hour to 2 lbs.; from £40 freights for steam to India to 40*s.*; from 108,321 tons of steam shipping belonging to Great Britain in 1850 to 1,847,588 tons in 1875; from a 10-knot speed to 15; from wood to iron; from iron to steel; from 6 beams to 10, with equal safety and greater comfort; from misery to passengers to the nearest approach to luxury that could be expected at sea. He utterly denied the Author's statement that monopoly was a bad thing and had done more harm than good. Young trades, like young trees, required protection, which however was injurious to both after they had attained maturity. At first it was impossible to set on foot such enterprises as those of the Atlantic steamers without some such

protection as had been given to them. There was a good deal more work of the same kind to be done, and he should be sorry to see a principle accepted which would put a stop to the most unobjectionable form of Government interference. The interference of the Board of Trade was only injurious when it took the dicta of men of high standing and great experience, and transformed 6 to 8, as factors of safety, into lbs. per square inch. When new materials were obtained, or a new disposition of those materials, it was clear that the 6 to 8 factor would remain true and correct; but when translated by the Board of Trade into so many lbs. per square inch the interference became a very unwise one. There was, no doubt, a tendency to over-legislation —to consider every man a rogue until he had been proved to be an honest man, and the result was that many men found themselves forced into a corner, and had to compromise with honesty. The Author had principally complained that there was not sufficient advance in economy to enable the trade of which he had spoken to be carried on at a profit, or that the profits were very uncertain. The diagrams and tables placed by Mr. Perkins on the walls, however, afforded an answer to everything that he could say on that subject. It was to be regretted that Mr. Perkins had not spoken more fully of his invention, but he was known to be a very modest man. Admiral Selwyn was himself one of those who looked forward to progress in steam shipping as the only means by which the country could maintain its position. He knew that in that Institution there could be no sympathy with the idea of "rest and be thankful." Mr. Perkins had asked him on one or two occasions to go with him in his little steamers. The only thing that astonished him (for he had studied the subject before) was that the engineer desired nothing so much as to blow up his boiler. He had himself turned the steam on the back of his hand at 500 lbs. pressure, and it produced a sensation rather of cold than heat. Here was a boiler which, by the new disposition of material alone, had achieved that safety for which all had been looking, under very high pressures, while at the same time it had achieved durability. At those high pressures and under that condition of steam peroxidisation took place on the interior surface of the tubes, and they remained the same after thirteen years' wear. It was no new thing; it had been proved by a Boiler Committee, who had stated that it was the only known solution of the problem; yet the thing did not seem to go forward—he hoped only because it was not more widely known. The economy of fuel obtainable by this boiler,

which required only 1 lb. of fuel per indicated HP. per hour, was easily understood, when it was remembered that instead of a water-box at a temperature of about 220°, with the highest pressure in use at present round the combustion-box, there were a number of tubes containing steam at a much higher temperature, much more nearly approaching that of combustion. There the fuel could be got to burn as it ought to burn, which it never did before. The burning of the fuel was also conducted in a boiler of much smaller size than any previously used, when they were considered simply as water-boxes with fires inside them. It was also a great advantage that it could be supplied with a casing filled with vegetable black, which prevented the heat being felt in the stoke-hole. Naturally, from engines, though they might be jacketed, there would be a certain amount of heat; but if the boilers were properly constructed, there would be no reason why the stoke-hole should not be even cooler than the engine-room. Taking 5,000 lbs. pressure on the inch as the test, he presumed the idea would be dismissed that even if the boiler could burst, it would be likely to burst at 500 lbs. pressure, at which it was intended to run; but when it was remembered that even if it did burst, one tube only was spoiled, and all the gases inside escaped almost without noise, and certainly without damage to the vessel or crew, it would be admitted that that was an enormous advance. With regard to the compound engine which the Author had put forward as the great improvement during the past twenty-five years, he had spoken of it when it was not in so much favour as it appeared to be at the present time, but he never made the mistake of thinking that the compound engine was the real source of the economy. He had known from the first that it was due to nothing more than increased pressure, and that if improvement was sought it might possibly come to pass that the compound engine would be done away with altogether; it might be found that while the pressure in the boiler was increased economy was obtained, no matter what kind of well-devised engine was employed to develop the power. His attention had been drawn for some time past to the causes of decay in boilers, and he found himself obliged to acknowledge that there was a chemical action going on which had not been spoken of before the Committee on Boilers, or in any other way. He had studied the matter in some chemical works, and believed he was able to give a consistent explanation of the causes of that curious form of decay in boilers called "pitting." It would be found in Watt's Chemistry, and elsewhere, that chlorine invariably passed over as an accompaniment of the

distillation of salt water, and it attacked certain parts of the boilers which were not homogeneous, and were more liable to its effects than other parts. Having so attacked it the water-vapour present, particularly at the higher temperatures, transformed the chloride immediately into an oxide, liberated the chlorine again, and enabled it to recommence its action; thus pitting might go on at one spot completely through the boiler. The ordinary way of preventing it was to let a small scale get on the boiler, but that was an unsatisfactory method. It was better to understand the chemical part of the question, and to know what to prepare for, than it was to injure the heating surface in some parts in order to protect it in others. With regard to the outside, of course it only took the place of any other preventive of radiation, but with reference to fire-boxes, a very thin coat of scale produced evil effects, which ought by all means to be avoided. There were several experiments, some of which had been made by Mr. Bramwell, showing that in the boilers on the Perkins system used for heating water in houses, and for other purposes, on opening the boiler after a given time of running, there was an escape of pure hydrogen. That hydrogen certainly did not come in through the pumps as gas; it came because at the high temperature to which it had been exposed water was so far decomposed into its constituent gases as that the oxygen could combine with the iron, with vegetable substances, or with anything for which it had a greater affinity at that temperature, and which it was usual to call "scale preventers" and "boiler protectors" when they were put in. Thus combining, the oxygen deserted the hydrogen, and that, he thought, was the only way to account for the presence of the latter in the uncombined state. For the present he submitted it rather as a theory than as a proved fact; but in the current number of the "Engineer" an account would be found of experiments in America devoted to the proof of what he had stated. If Mr. Perkins's boiler would give high pressures (the necessity for which appeared to be universally acknowledged) without danger —if it gave to naval officers the power of repairing boilers at sea and without cutting their ships to pieces, and gave at the same time an engine requiring no lubrication, and occupying a comparatively small space, if by a little chemical attention any defects that might arise (which, however, Mr. Perkins asserted would not arise) from ordinary leakage in the fresh water originally supplied might be remedied, the subject surely was not unworthy of the attention of the reader of a Paper on the progress of steam shipping, and might give him reasonable ground to hope that all previous improve-

ments might be thrown into the shade by what we now actually have in our own hands. The matter, he was happy to say, was no longer in the domain of an inventor's unaided efforts, nor even of Government solicitation; it had passed into the hands of a gentleman, Mr. George Crawshay, whose name was well known for actual practice.

Mr. COWPER would have been glad if the Author had descended a little further into details; the mechanical part of the question being of more interest to the members of the Institution generally than the commercial part. There were several steps, however, in the progress of improvements that took place more than twenty-five years since, and to which he should like to refer. The Author had mentioned three steps—iron ships, the screw propeller, and the compound engine. With all deference he ventured to suggest, that the raising of the pressure of steam was at least as important as any one of those three steps; certainly as important as the compound engine, because without it the expansion could not have been carried so far as it had been, and such powerful engines could not have been constructed in so small a space. A beginning was made as early as 1835, when Spiller's boiler first came out, capable of containing working pressures of 5, 10, and then 24 and 40 lbs. Mr. Spiller, with Mr. Zander, had a small boat called the "Era," with an engine working at 40 lbs. pressure, and they had also a compound engine with a small cylinder to one crank and a large one to the other, and the cranks at right angles, as far back as 1841. Steam navigation might certainly be said to have begun in 1836. Before that time Dr. Lardner had prophesied that the Atlantic could not be crossed; but in 1836 the "Sirius" and the "Great Western" actually did cross it. Then came the "British Queen" in 1838, the "President," the "Archimedes" in 1840, and the eight Royal Mail steam packets in 1841. Spiller's boiler had water inside the tubes and fire outside, and they soon gave rise to the present form of marine boiler, with water outside the tubes and fire inside. One of the earliest was made by Mr. Maudslay, and others were made by Mr. Braithwaite. His "Prince Albert" had Spiller's boiler at first and then the marine boiler. The boats he had referred to were all driven at a greater pressure of steam and going at a considerably higher speed than before. The "Princess Alice" was another of Mr. Maudslay's boats which did well. Then came the quick boats on the Thames, and afterwards the first fast Mersey boats. By 1846 the old Spiller boiler had gone, and the marine boiler had taken its place; but before this, his friend, the late Mr. Alfred Milner, had made a marine boiler

with fire in the tubes, and with a cylindrical shell for 30 lbs. pressure; this boiler, when sold as second hand, burst from bad treatment at considerably over 100 lbs. per square inch, so that strong high-pressure marine boilers of a reasonable shape were made as early as this. The Samuel Hall's surface condensers, invented in 1833, followed, though not much in use before 1838, when they did good duty in the "British Queen," after which more attention was paid to them. Later on, steam jackets began to be used to a limited extent, as the advantage to be obtained by their use was not then fully understood. The "Link-motion" was another good step in improvement. The common form of compound engine, with a small cylinder to one crank, and a large one to the other, the cranks being at right angles, succeeded. A friend of his had such an engine in use on land about 1844, and several times the low pressure engine was entirely broken down from the high-pressure steam getting through from the high-pressure engine into the low-pressure, and he requested him to put the matter right. He accordingly put a steam-jacketed "steam reservoir" between the two cylinders, and he believed that was the first time that such a steam reservoir had been used, although now they were so common, and did such good duty, entirely preventing the low-pressure engine ever being strained when the reservoir was properly fitted with a large safety valve. The engine was successful, and he afterwards introduced the same contrivance into other engines on board ship, and on land. He also had the honour of persuading Mr. Elder to put the cranks at right angles, a process attended with great effect, obviating the necessity of having six cylinders, two to each engine, but simply requiring two cylinders, one to each crank. Then the "Briton" and the "Thetis" were fitted by Messrs. Rennie on Mr. Cowper's plan, and in those vessels the saving which the Author looked for, during the next twenty-five years, had been actually accomplished. Instead of 2 and $2\frac{1}{2}$ lbs. of fuel per indicated HP. per hour being reduced 20 per cent., a reduction had been already made from 27 to 35 per cent., for they had worked full speed at 1·98 lb. of coal, and at 10 knots at 1·3 lb. The steam in such engines should be cut off and expanded in the high-pressure cylinder, and should always be cut off at or before half stroke in the low-pressure cylinder, otherwise a second portion of steam from the high-pressure cylinder passed into the low-pressure cylinder, thus uselessly filling up space, and throwing away power. If the steam was cut off at half stroke in both cylinders, the most uniform power attainable was produced. The Author had held up the

compound engine as one of the grand steps that had been taken in late years (and so it was); but he wished to ask, whether he had not, since 1872, had many engines with single cranks and a fly-wheel. He believed fly-wheels, about 12 feet in diameter and 7 tons weight, had been found very useful for getting over the centres, but they would hardly have been found satisfactory in practice without a very quick and effective reversing motion, consisting of an ordinary "link-motion" moved by a steam cylinder, moderated in its action by a "cataract," or water or oil cylinder, which rendered it very easy work to handle the engines. He thought that the members would be glad of the opportunity of discussing that form of engine if the Author thought it a better one commercially than a compound engine with a single cylinder to each crank, and the cranks at right angles. He was informed that many of them had been made, and that more were still being made.

Mr. J. L. K. JAMIESON said that all practical men connected with marine engineering would acknowledge that they were under a debt of gratitude to the Author for bringing forward so interesting a subject. They would also, he thought, agree with him that nothing had contributed more to increase the commerce of the country than the compound engine as applied to the propulsion of ships. If there was any point on which he would be inclined to find fault with the Paper, it was that the Author had not given sufficient credit to two men, John Elder and Charles Randolph, who had fought the battle when there were few people to help them. It was in 1854 that the screw steamer "Brandon," fitted with their compound engines, went to sea, and in 1856 the paddle-wheel vessels "Inca" and "Valparaiso," fitted with compound engines, were sent to the Pacific. There were few people who knew the history of the compound marine engine so well as himself, having been Superintendent Engineer for ten years of the Pacific Navigation Company in the Pacific, and having been connected since that time with Randolph, Elder, and Company, and the firm of John Elder and Company. The diagrams, taken from the engines of the "Bogota" in 1860, with two 48- and two 90-inch cylinders, and 5 feet length of stroke, indicated nearly as good results of any that could be obtained of engines in use at the present time; the pressure of steam was 25 lbs. in the boilers, and the condenser was of the ordinary jet description. The consumption of coal was 2½ lbs. per indicated HP., and might be considered a good result at an early period of the compound engine. Owing to an accident happening to one of the low-pressure pistons, the engines of this vessel were worked for several months with three

cylinders, and the diagrams shown from the high-pressure cylinder of the disabled engine would be considered a good figure from an ordinary low-pressure condensing engine. Whilst the engines were working in this condition the speed of the ship had been reduced, and the consumption of fuel increased about ¼ compared with the performance of the four cylinders, thus showing a marked economy in favour of the compound engine. The history of the compound engine and its rapid adaptation to all classes of steam ships were now well known, but he wished to support the Author's appeal to the members against too much Government interference, and the necessity of protesting against it. There was no such interference by the Board of Trade twenty years ago, and if there had been he was firmly of the opinion, that compound engines would not now be in use for the propulsion of steam ships. The interests and the reputation of marine engineers throughout the country were at stake. At present it was impossible to move out of the track the Board of Trade had instructed their surveyors to keep without encountering difficulty and annoyance. He had no fear of progress being made in the future in marine engineering, as well as had been done in the past, if the individual talents of those engaged in it were left unfettered. The Institution of Civil Engineers might do much good by protesting against such interference as limited the individual talents of the engineering profession, and presented that progress which was likely to take place when not cramped by a Government department. It might be necessary to bring the whole matter before Parliament.

Mr. Moy stated that up to the present time the great aim of the marine engineer had been to produce the highest possible figure of indicated HP. per lb. of coal consumed. But Mr. Froude had brought to the front another important item, which must never again be neglected, namely, dynamometrical thrust. He had roughly sketched a vessel, in which the indicated HP. was marked as 10, while the useful effect was represented by a weight attached to a rope and the figure 4. Suppose the engines to be consuming 2½ lbs. of coal per indicated HP.; at 13 knots an hour this would represent 10 lbs. indicated thrust per lb. of coal, but the useful effect was only 4 lbs., that was 4 lbs. multiplied by 1,320 feet per minute was all that could be got out of 1 lb. of coal. It therefore became very important, not only to obtain the highest possible indicated HP. per lb. of coal, but also to reduce the enormous difference between these two figures 10 and 4. That friction of machinery had much to do with this result there could not be a doubt; but he thought that the screw was very much at

fault, and he would endeavour to point out one of its faults. The case of a right-handed screw propeller might be considered, the ascending blade being on the port side, and the descending blade on the starboard side. The pitch being the diameter multiplied by 1·25, the angle might be about 22°, or 68° from its line of axis. Now if all the water about the run of the vessel moved in parallel horizontal lines, this propeller would act as desired. But the water would not do so. The current approached the screw obliquely, and the screw acted on that oblique current in a manner not intended. The water rushed up under the vessel, approached the port blade at right angles, and at some speeds it would simply have a back action instead of a propelling action, because, relatively to the current of water, it had no pitch at all there. On the other hand, the starboard blade, when in a horizontal position, struck the ascending current of water at an angle of 44°, the pitch being increased to about three times the diameter. At the intervening points in the circle the blades acted obliquely on the ascending current. He thought, therefore, that the effect which he had attempted to point out accounted for a considerable portion of the 60 per cent. loss which was sustained, and it also accounted in some cases for what was called negative slip and the loss of many propeller blades. The remedy was to place the propeller shaft in a line with the natural current of the stern water, and the propeller, of course, square to it. It would be necessary to get rid of the awkward construction called "screw alley," to have a short and strong propeller shaft, and to reduce the 60 per cent. loss, and that meant less power, and therefore coals saved. He thought his point was proved by the success which had attended the trials of Griffiths' tubular screw channels, for they directed the current square to the propeller. About twenty years ago he proposed making the upper end of the rudder the broadest part: he now ventured to put it also square to the stern current, and to attach the tiller to the after end of it.

Mr. JOHN DONALDSON said that the Author had confined his attention to vessels in the merchant navy to the exclusion of vessels built for purposes of war, owing, no doubt, to the fact that the improvements referred to were applicable to both classes of vessels, and that the results of their application were obtainable in both cases. Of late years, however, a new type of war vessel had arisen, and it would be a pity that the discussion should close without some notice being taken of it. He alluded to the fast steam launches designed by Mr. Thornycroft some years ago, which were now being made with some modifications by his own firm as torpedo vessels for the

English and several continental navies. They were similar in many respects to the vessels described by the Author, being built of steel, and fitted with compound engines and surface condensers, and having, what the Author desired so ardently, locomotive boilers, with steam at 120 lbs. pressure, and also with spring safety valves. Strangely enough the proportions that had been found by the Author to give the greatest economy in vessels in the merchant navy had been proved by his firm to be best adapted for high speeds. Their vessels were usually about $7\frac{3}{4}$ beams in length, and Mr. Froude, in some experiments on the "Lightning," had shown that that size gave the best results. In the 58-feet type they had attained a speed of $15\frac{5}{8}$ knots per hour, in the 67-feet type 18 knots, in the 76-feet type $18\frac{3}{4}$ knots, and in the 84-feet or "Lightning" type 19·4 knots when the vessel was light, and $18\frac{5}{8}$ knots when she was loaded. There were no very accurate data with regard to coal consumption, the efforts of the firm having been chiefly directed to the production of high speed. The results he had mentioned were not founded on mere measured-mile trials, but on runs of from one to two hours' duration. In some vessels which they were completing for the French navy they had undertaken to maintain a speed of 18 knots per hour for three consecutive hours. In their early steamers the blast was laid below the fire-box, but it was found that this gave rise to many inconveniences. Ultimately they closed up the stoke-hole, and forced the air into it, so that the only exit for the air was through the furnace. In some of their vessels his firm had used 8 inches water-pressure in the stoke-hole, when they had been rather pressed for steam; but their best results had been obtained with about $2\frac{1}{2}$ inches water-pressure. He had heard of the excellent results obtained by the Author's steamers while in the East, and should be glad if the Author would give some information with regard to coal consumption, and also the proportions of his vessels and engines.

Mr. J. MacFarlane Gray said it had given him great pleasure to listen to the Paper, because, in addition to the high value of the statements it contained, it happened that, when the Author began to use compound engines, Mr. Gray, then with a Liverpool firm, had to see his first design carried out in the first engine of the firm, now known as the Holt engine. One of the speakers in this discussion had tried to make out that the Author was more of a shipowner than he was either an engineer or a shipbuilder; now he would take this opportunity to state before engineers that the Author was also so much of an engineer, even in points

of detail, that the design for that first Holt engine was substantially complete in arrangement and proportions as it came from him. He thought that the forecast of probable further reduction in the cost of the HP. as stated by the Author was a very just one, and none could give from better information what had been the rate of improvement in the past. Although he concurred in the Author's views he would not say one word to take away from the sanguine anticipation of Admiral Selwyn, because he thought there was really no difference between the two. The Author, no doubt, reading the practical lesson contained in the experience of the "Propontis" and other experiments in higher pressures had concluded that doubled or quadrupled pressures were not for his steamers in the immediate future. If the higher pressures shown to be so very manageable in the Perkins boiler were commercially practicable, then the economy anticipated by Admiral Selwyn would no doubt result. From 20 lbs. of coal per hour with surface condensation there should be obtained the following, 6, 8, 10, 12, 14 HP. at 40, 80, 160, 320, 640 lbs. absolute pressure. The first two steps in this series are taken from the Paper. If in addition to the higher pressure there should be also an increased furnace efficiency, giving a higher rate of evaporation per lb. of fuel, then 500 lbs. pressure might give double the present efficiency or 16 HP. from the 20 lbs. of coal per hour, which, according to the Paper, now gave 8 HP. A great deal might be reasonably expected from the arrangement described by Admiral Selwyn, and he hoped that the Author would turn his attention to it because if it was a practicable system it would then probably soon be fairly tested in a merchant steamer. Admiral Selwyn had stated that the Perkins boiler was found to contain much hydrogen when it was opened after long use. The decomposition of water vapour in contact with iron at ordinary steam temperatures was a fact not so generally known as it ought to be to engineers. He had heard Professor Frankland state that this decomposition never occurred but at a temperature very much above what occurred in the steam boiler. The hermetically-closed spaces of steam pistons after the engine had been in use a year or two, contained so much hydrogen that explosions to the injury of workmen had frequently happened. The first time he had this brought under his notice was about 1863, in Liverpool. A man boring, to put in some additional bolts for a junk ring, lost his sight through the gas in the piston exploding when it came in contact with the flame of a candle. Several other similar instances had been reported to him. With reference to engines not compounded, competing in economy with

compound engines, engineers naturally looked to America where the long stroke single cylinder was doing good work. It had been his good fortune to be present, during her first trip, on board the "Hudson," a steamer of this description lately illustrated in the "Engineer." There were two circumstances in connection with that vessel well worthy the attention of the engineers of this country. Here the bearings had their keeps fastened with large bolts having threads of a coarse pitch. When a bearing became heated an engineer was apt to slack back the nuts too much, and often the heating was thereby increased. In the "Hudson" and the other vessels of the same company the old form of gib and cutter had been retained, and one turn of the small nut at the end of the cutter would alter the distance of the brasses perhaps only 0·02 inch. The fine adjustment led to great carefulness on the part of the engineer. This means of accurately setting up the brasses would be of no avail unless time were given to enable the engineer to try what was the best distance for the brasses. The owners studied this need, and the first trip of the "Hudson" was made with only half the boilers in use. The first voyage it was intended should also be made with only half-boiler power. The object of this was to give the engineer time to deliberately adjust every bearing without being troubled with several hot bearing at the same moment and to get the engine to work without the slightest thump. The engineer of the company, Mr. John Baird, a gentleman who was most willing to give every opportunity for inspecting the engines to engineers from this country, explained to him that their company, the Cromwell Line, never hurried them in getting up the speed. They knew the speed would be the greater when they did get it if it took six months with reduced boiler power to enable them safely to get up to it. How strange it would seem in this country if an Atlantic steamer intended to beat all others in speed, should be sent several voyages with her boilers not all in use, and her first voyage with only half-boiler power! It might, however, be a wise course to follow, and it would lead to the saving of thousands of pounds in repairs. It was not only that the bearings were scrupulously cared for after they were in the steamer, they were finished in the lathe with even greater care. Every bearing of the crank shaft was finished absolutely true with the corundum wheel, and this was carried out to exactly the same degree of accuracy as was their practice with the rollers for paper mills. He spoke according to what he had seen and tested at the works at Wilmington, where the engine of the "Hudson" was made. In the course of this discussion, Mr.

Froude's conclusions on the ratio of useful effect obtained had been referred to. In the sense in which "work" was understood in mechanics, there was really no useful result whatever obtained from the marine engine, and there was therefore no fraction of the power applied which was absolutely unassailable for increased economy. Mr. Froude had shown how great was the loss by friction in the moving parts of the engine, and the American engineers seemed fully to appreciate that fact, and to be taking the best way of reducing that element of loss. In the principle of the engine he thought the American single engine for the screw propeller inferior to the English compound engine. He formed this opinion from examining the diagrams taken from the "Hudson's" engine. The excellent result undoubtedly obtained was, he believed, in a great measure due to the diminution of loss by friction in the engine by greater accuracy of workmanship and extravagant carefulness in working. The Author had spoken disparagingly of steam jackets and indicator diagrams. Steam jackets ought not to be indiscriminatingly dealt with as if all were under the same conditions. About twelve years ago in Liverpool an assistant of the Author and himself received from the manager of the works of Gebrüder Sulzer, of Wintherthur, a careful statement of results obtained from an elaborate series of experiments made to settle the steam jacket question. The pith of the conclusions was that up to four expansions in one cylinder a steam jacket was of no advantage. When the multiple of expansion exceeded 4 the advantage of a steam jacket became apparent. As in the Author's steamers the expansion in one cylinder did not exceed the ratio 4, this experimental deduction did not seem to be interfered with by the Author's experience. Indicator diagrams must also be treated discriminately; he had implicit faith in diagrams, but he seldom met with any one who understood them. He had questioned hundreds of engineers on diagrams, but he had seldom found one who could read off from a set of cards what the effective pressure was at any marked point in the stroke. This state of knowledge perhaps accounted for the little faith some engineers placed in the diagrams. A valuable illustration of the usefulness of diagrams had frequently come under his observation. Some of these also revealed how a steam jacket might possibly become a real evil. In the complicated castings of which jacketed cylinders sometimes consisted, a core plug was perhaps left out; or a contraction crack might exist which, when the cylinder was examined, might be so close that it was invisible, and even almost watertight under hydraulic test.

If such a crack occurred in the division between the steam jacket and steam ports the current of steam soon cut it wider. He had seen such a crack about 20 inches in length widened by the erosive action of the leaking steam, at the end of five or six years, to be about $\frac{1}{4}$ inch open at the middle. The diagram revealed the existence of this leak and indicated its locality. About boiler strength, the Author had been very severe upon the Board of Trade, and he had on a former occasion in a printed Paper, compared the practice in America with the pressures allowed by the Board of Trade, to show that the restrictions of the Board were oppressive to engineers and shipowners. Mr. Gray confessed to sympathising heartily with the Author and with every engineer who desired to make the most of his materials. It must be evident, however, that the feeling expressed in this discussion very much preponderated towards the stringent inspection authorized by the Board of Trade. In America, also, he was astonished to find that the engineers of eminence on the East Coast were almost all in favour of the proportion of strength prescribed by our Board of Trade. In the Western States the boilers were much lighter than ours, but the boilers now making on the East Coast for pressures, equal to those in use here, were substantially what would be passed by our Board of Trade for the same pressure. Some of these boilers had to pass also in this country, and it might be thought that this explained that fact. The war vessels, however, could not be meant to pass our Board of Trade inspection, and the eight vessels of the "Swatara" class, each with ten boilers for 80 lbs. pressure, had these boilers, substantially, just what would be allowed 80 lbs. pressure in this country. This statement was made upon personal inspection of these boilers in course of construction.

Mr. HOLT, in reply, said he could at least claim for his Paper the merit of having provoked a very interesting discussion. Mr. Samuda had taken him to task for not having given honour where honour was due, and mentioned the name of Mr. Brunel. He desired to give a fair meed of honour to every one who had earned an honourable place in this great though unnoticed revolution, and if he had failed to do so he wished to make amends. He thought it would be a fitting thing for the Institution to have a record made before the facts were forgotten, for there were many persons who had rendered marked assistance, and whose names were seldom mentioned. Whether the compound engine could be traced back to Hall of Dartford he did not know, but he thought it probable that it could be so traced through the various steps of

Elder and Hick, who competed with Hall, at an early date, for the manufacture of compound engines for land purposes at Barcelona. Nor should the name of Arthur Woolf be forgotten, who enunciated the principle as early as the beginning of the century. Mr. Brunel deserved great praise, if only for the "Great Britain," an admirably built vessel, in which he made an excellent experiment with the screw, at a time when it was much wanted; but with regard to the "Great Eastern," he thought size was her chief peculiarity, and that there was not so much to learn from her as from other vessels. Considering Mr. Brunel's genius and the flow of capital his designs attracted, his only wonder was that she was so small.

At the request of several speakers, and not that he claimed for it any peculiar merit, he would now briefly allude to his own practice. When compelled to greater economy in fuel, he noticed that in many places the single engine was employed with absolute satisfaction; that in cotton mills, where regular turning was more necessary than in any other case, the single engine was frequently used. He had also observed that in America it was almost invariably used, and he accordingly resolved to try it. His first idea was economy of cost and space, and he believed that he gained in both. He had fewer parts, and fewer expensive and dangerous parts, the crank shaft particularly was much simplified. He apprehended at first some difficulty in handling and some risk of collision from not being able to reverse the engine when required; but every apprehension of that sort had turned out groundless, and having now had considerable experience with the single engine, and moderate experience with a double one, he thought that the former was rather more handy than the latter. Allusion had been made to a probable irregularity of motion owing to the force exerted by the engine at one part of its stroke being about one-third greater than the average force. That was so, scientifically, but he had never been able to perceive it, and he believed that the single engine turned the screw as regularly as the double engine. He made that statement after having watched them both attentively for a long period. He had always aimed at as long a stroke as possible, and a fair speed of piston, say from 400 to 500 feet per minute, according to circumstances, and light, strong, moderate-sized parts. He believed that a great deal of the power that was lost, and which loss found no expression in the indicator diagram, resulted from the great weight of the parts. He had been led to that conclusion by a simple experiment. If any one would take a heavy dumbbell in his hand, and try to work it quickly

backwards and forwards, he would find that there was an enormous expenditure of power, and he concluded the same was true of engines. He had been told that in some large steamers there were pistons 110 or 120 inches in diameter, weighing nearly 9 tons, with piston rods, cross heads, connecting rods, and other parts attached to them weighing altogether as much as 15 tons. Imagine a small locomotive in weight the equivalent of such a mass, brought to rest from a speed of 8 miles an hour in a space of 2 feet, and this repeated every half second. He imagined that by any one riding on it the process would be called a series of rather severe collisions. He could not but think that an enormous quantity of power was expended in this way, and he had accordingly aimed at lightening and strengthening the moving parts to the utmost. He had not aimed at extreme expansion, because it involved large parts. From 5 to 7 times was the expansion he had adopted with 70 lbs. pressure of steam. His engines were furnished with a fly-wheel, which was a very useful adjunct, even to a double engine. Damage had been apprehended from the use of high-pressure steam in the working parts. It had often occurred, and it had proved a difficult thing to get over. He had used for the high-pressure engine with success plug piston valves—simple plugs moving up and down, which were very nearly tight. He could not detect on the indicator diagram much leakage; they certainly required no power; and there was no liability to the cutting which often took place on high-pressure valve faces. His ships were from 1,900 to 2,300 tons, about 9 beams in length, with a depth of a little less than $\frac{3}{4}$ of the beam. They were rather finely modelled and lightly rigged. They were all in the China trade, and he believed his was the longest voyage in the world, being from 22,000 to 23,000 miles. He had noticed that one of them during a China voyage had had her sails set only seven hours, which caused him to conclude that he might safely rig his vessels lightly for the future. He had always provided ample boilers, and might say that he had never over-boilered or under-masted a ship. He obtained a speed of about $9\frac{1}{4}$ knots from a consumption of from 14 to 17 tons of coal per day on a voyage involving about one hundred days' steaming, and in consequence of consuming so small an amount of fuel he was often able to do the whole of his coaling in England. Mr. Merrifield, in commenting on the statement that carelessness about further coal saving was coming over shipowners, said that probably Mr. Holt was like the rich man who did not care about the quantity of bread consumed in his household. He denied the application of the simile; but if he, on the longest voyage in the world, was

beginning to forget the coal bill and direct his attention rather to other disbursements, it would only be natural that shipowners engaged on shorter voyages should be more careless still. Anyway the fact was becoming apparent that shipowners were now thinking less of coal consumption than they did only a few years ago. The recent fall in the price of fuel might have a good deal to do with it. He found that on the voyages to China the dues paid by him were sometimes 50 per cent. greater than his coal bill, and he only wished he could apply the compound principle to the Suez Canal. When hinting in the Paper at the probability of the single engine replacing the compound engine he had very much in his mind the practice of Mr. Baird, to which allusion had been made by Mr. MacFarlane Gray. The performances of the "Hudson" as set forth in the "Engineer" were certainly very wonderful, and he only wished he could be certain that they were correct. He believed, judging from the size of her boilers and furnaces, that the consumption would be about 26½ tons of coal a day; but the amount stated in the "Engineer" was 17 tons. He was of opinion that the danger arising from the admission of steam in a single cylinder, which seemed to haunt English engineers, was a phantom. In a well-constructed engine steam might be admitted at high pressure, on a moderate-sized piston, without injury. Probably one reason for the prevalent shortness of stroke in this country was the difficulty in forging crank shafts. If a 6-feet stroke like that of the "Hudson" were desired, the forging of the crank shaft would be a very serious affair. It was a question with him whether loose cranks would not come into use again. He remembered the time when all screw steamboat engines had loose cranks. Although the intermediate bearings might be a little sore, they never broke a crank or a crank shaft in those days. If the engines were placed a little farther apart, so as to get a long intermediate shaft and bearings sufficiently remote to be tolerably steady, the old system might still be found the best, and it would allow any stroke that might be desired, and also would admit of moderate-sized crank pins. Mr. Froude had spoken of an engine with a crank pin 22 inches in diameter and the same in length. All he could say was that a crank pin of that size could come to no good end. He had taken a voyage up the Mississippi in a vessel in which the steam was at 150 lbs. pressure, and the engines had two separate cylinders 32 inches in diameter and 12 feet stroke. Steam was allowed to remain on the piston about ⅔ of the stroke. That immense power was all taken through a 5½ inch crank pin, and it stood perfectly,

and kept quite cool, although no particular attention was paid to it. With reference to the indicator, the opinion he had expressed with diffidence was that it could not be implicitly relied upon. Much of the power shown by the card did not find its way to the propulsion of the vessel, probably because it was taken up by the actuation of the piston, and other heavy parts first in one direction and then in another. And again, if the indicated HP. was made up very largely of high speed of a short-stroked piston, or of excessive expansion realized only by large parts, he doubted that the power shown did not produce its due effect. Nevertheless the indicator was certainly a most useful instrument for finding out faults. He had been asked to account for his statement that boilers of the present high-pressure vessels were as durable as the old ones. He could only say that he had found them to be so. Very recently he had sent a vessel to sea which had nearly completed ten years' constant service, made by the house of which the President of the Institution was the head. It was originally designed for a pressure of 60 lbs. of steam, and was tested before going to sea on the present voyage with water pressure, and stood 100 lbs. without sign of failure. He could hardly perceive that the boiler wanted anything doing to it. Probably if one-eighth of it were renewed it would be as good as new. Mr. Flannery had justified the discrimination alluded to in the Paper, namely, that if a pressure of 120 lbs. was carried by the boiler of a locomotive, one of 70 lbs. would be a fair pressure for the same boiler at sea, and had said that the different uses of the two justified the discrimination. He joined issue with Mr. Flannery on that subject. He had inquired into the construction of a good many boilers, and found that every part of every boiler that he had got, except amongst the tubes, could be seen by an inspecting engineer with moderate ease. That could not be said of a locomotive. His knowledge in regard to locomotive practice was of rather old date, but it was formerly the custom to use locomotives without seeing the inside of the barrel until six or eight years had passed. He did not know whether that was the present practice, but certainly much more care could be taken, and he thought was taken, of steamboat than of locomotive boilers. It used to be said that in a fire-box, if the screw stays were recessed, so that there was a bulge between them, it was a matter rather to be proud of, because it was said the stays were coming to their bearings; if such a thing were seen in a steamboat boiler it would be remedied at once. With regard to the factor of safety for steamboat boilers he confessed that his mind had undergone a considerable change. He

had originally thought that 6 would be a fair figure, and that the Manchester Steam Users' Association, the Philadelphia Association, Locomotive Engineers, and others, were wrong in giving 4 and 3½: these asserted, however, that they had never had an explosion, and what more could any one want? Therefore, guided by the light of their experience, and considering the ease of examining steamboat boilers, he thought that a factor of 5 or even, after trying that a few years, a lower figure still might be safely adopted. Of one thing he was quite sure, viz., that the tension allowed on straight stays, 5,000 lbs. per square inch of section, might reasonably be almost doubled. It had been said that the factor of 6 or even 8 was the origination of Sir William Fairbairn, but it was no derogation to him to say that in his later years he was slightly inconsistent in this matter, and that if at one time he had given those as suitable factors, at another he had recommended much lower ones. With reference to the rules of the Board of Trade, except as to details and questions of degree, he did not find great fault with their principle but it was ten thousand pities that they had ever been issued, for they stereotyped and gave authority to questionable opinions on very debatable subjects; and on one point of principle he disagreed with them, viz., when they assumed the shearing strain of rivets and the rupturing strain of plates as equal. He was well convinced that the former was the greater. In his allusion to the action of Government in his Paper he was sorry that he had struck a chord that had awakened some feelings which he did not desire to arouse. He had, however, a heavy indictment to bring against subsidies, which had been to him a rock ahead through life. The system began about 1840, and some of the subsidies granted put an end to independent lines just coming into existence. Subsidies had thrown back the use of the screw propeller ten or fifteen years. The "Great Britain" was built in 1840, and though she was not perfect, she afforded a very fair trial of the screw. After one or two more trials it would almost have attained its present perfection; but simultaneously the system of subsidies was started —and it was the natural desire of all the holders of subsidies to pursue the safe, and avoid experiments—and hence they clung to the paddle wheel, knowing exactly what it might be relied on to do, and that though an imperfect wasteful instrument, its performance was accurately calculable. Subsidised lines in those days of few steamers naturally formed public opinion, and the result was that between 1840 and 1855 any one who used a screw propeller in a vessel of importance was considered a harebrained

experimentalist, not to be trusted. Subsidies could also be shown to have delayed the use of iron vessels many years. People would not have the boldness to differ from the great steamboat owners, who themselves would try nothing new, and hence fleets worth millions sterling were built, their designers and many of their owners well knowing that the vessels were not of the best description. Amongst them he might mention such vessels as the "Orinoco," "Arabia," "La Plata," "Parana," "Africa," "Amazon," "Demerara," "Asia," "Magdalena," &c. The duty of the Government in this matter was a narrow one. Imperial necessities must override private interests, but tenderly, and with steadfast aim to postal necessities only. There should be no side aim to cheapen freights or passenger fares. Wherever the Post Office authorities absolutely required to have letters carried, and there only so long as they could get them safely carried, it was their duty to do so without regard to the establishment of a magnificent line of steamers which was often an instrument of oppression and the stronghold of mechanical error. It had been said that he was inconsistent, because he had made an offer to convey the West India mails in 1874. It would be affectation on his part to say that he would not get a subsidy if he could, but the facts of this particular offer were as follow. He had been engaged in the West India trade years before that time, and had felt that the presence of subsidised ships was a serious disadvantage to other vessels; he accordingly thought that though he had left it, he would endeavour to relieve the trade of that bane, and he believed that the only escape for Government was that the letters should be carried in vessels that conveyed neither passengers nor cargo (the condition on which his offer was made), because then, the whole stream of commerce being uninterfered with, other vessels would speedily establish themselves into lines, and the Government at the end of his term need never have paid any subsidy whatever.

With reference to the question of inspection, it appeared to him that the Government and the public were at present pursuing an impolitic course. One half of England was setting itself to inspect the other half, and no one could tell what would come of it. He feared the process would in a generation or two result in an indisposition to undertake difficult enterprises, and would enfeeble invention. He had no desire to indulge in attacks on the Board of Trade, but every public body was open to reasonable criticism; he invited it for himself, and always thought a critic his best friend. The Board of Trade had entirely gone beyond statutory requirements. The intention was simply to have the opinion of

a surveyor as to the safety of ships, and not to enforce minute constructional regulations. By what plain motives could the action of the Board in the question of safety valves be accounted for? They had indeed admitted the use of springs, after years of incessant remonstrance, and spring safety valves were now employed; but under what circumstances? Such excessive size was required that the incredible fact on board his vessels was that the safety valves had about twice the area of the steam pipes. It was well known that at a high pressure steam passed with greater rapidity from an orifice than at a low pressure, yet if a boiler were made for 10 lbs. or 100 lbs., an area of ½ square inch of safety valve for each foot of grate bar would be the rule for both; the waste from that absolutely reasonless regulation was enormous. They had also insisted that the valve should lift one quarter of its diameter, and had thereby cast great difficulties in the way of designers, and all perfectly needlessly, for no such lift or anything approaching it in the remotest degree was ever required. The united action of the Board of Trade and the Legislature in the matter of safety valves had been mischievous throughout; there never was a difficulty on the subject yet with all the years of trouble they had given; a country blacksmith who called a boy from the plough to turn his lathe would to day make a safer, lighter, cheaper, less wasteful, and in every way better safety valve than their best. The Legislature, in a moment of philanthropy, had passed a law that all vessels should carry a lock-up safety valve. Mr. Thomas Gray had stated that the technical advisers of the Board of Trade disapproved of that law. He had been of a similar opinion for years, and there could be no doubt that a lock-up valve had led to the loss of life in the "Thunderer." A plain locomotive valve would have prevented the explosion.

The question of engineer certificates had been alluded to. He believed the enactment that they should have certificates had been injurious; he meant, had rendered steam navigation more unsafe. He of course could not tell what went on in public offices, but he believed the act was passed without public pressure at the instance of the Board of Trade, simply to enlarge their region of interference. There is no handicraft skill in being a steamboat engineer; a habit of constant attention to simple, somewhat monotonous duties, and the power to stand changes of temperature, were the principal qualifications required, and the present class of men, as a rule, did not, and were not likely to possess them. That enactment very nearly caused him at one time to abandon the trade.

He had been asked to indicate the direction he expected future improvements to take. At the head he put the endeavour, which he saw no reason to suppose would be unsuccessful, to obtain more effect from the boiler. A single ton of locomotive boiler produced as much steam as 6 tons of ordinary steamboat boiler, and some simple cheap mode of producing a keen draught without a steamblast (which was simply throwing away fresh water) was a desideratum. This more rapid combustion, if attainable, was evidently synonymous with a lighter boiler, carrying with it many savings. Next, the principle of hot blast, he thought, would come to the front, as a matter for probably successful experiment. Few persons appreciated the volume and heat of the current which went up the funnel, which, he suspected, though containing some carbonic acid gas, was mainly little else than hot air and unconsumed fuel; often this loss was accepted and increased as a simple mode of producing draught. Suppose this current were driven through a second fire, would not the hot blast effect be produced and the fuel burnt up?

The use of steel presented great attractions, the possibility of saving was so immense, but the question of reliability stood at present practically unsolved, he used the word "practically," because steel makers said it was solved; but they would hardly claim for the solution that it was not rather too delicate and scientific to meet general acceptance. Besides, he feared an objection would be taken to very light scantlings on account simply of their lightness. In hulls, more especially in skin plates —an amount of "obduracy" to be gained only by weight was required.

One of the greatest improvements in steamers would be the production of unbreakable shaft forgings; outsiders had hardly any idea of the cost, delay, and frequency of broken shafts. One recommendation he would give would be when a shaft broke to be sure that the bearings were in line, he feared untruth in them often broke shafts.

What future extension would the steam trade take? A slightly further invasion of the business of sailing ships might be looked for, but the principal extension would probably be in new directions. Generally speaking an increase in our enjoyment of the more perishable products of distant parts of the earth might be looked for. He took it that live cattle would be brought to this country in numbers hitherto unthought of. There was no mechanical difficulty in the way; the fear of government interference alone, he believed, stopped them being brought over from Texas

or the River Plate; there was no doubt some £5 from the former, and £6 from the latter would carry them if capitalists dared embark in the undertaking on a sufficient scale to make it successful. Oranges were a small matter, but this country was now beginning to have two annual crops instead of one as formerly, the second coming from south of the equator. A large extension in this class of trade might be looked for.

What it had not so far accomplished satisfactorily, numerous as had been the attempts, was the Channel service, and this was the more astonishing that the problem looked so easy. Whether the new "Castalia," a very fine and interesting vessel, will possess the four requisites—speed, steadiness, lightness of draft, and handiness—next year would solve.

He could not see that the future promised a better money result to the shipowner than the past. His would doubtless continue to be a business yielding different results to differing managements; but that the past average result, which he took it had been from 3 to 5 per cent., would be much exceeded in the future, was what he would wish and hope, but could not expect.

Mr. STEPHENSON, President, said, with reference to the indicator, statements had been made as to what it could not show, and it was only fair to the inventor to state what it could show. He for one believed thoroughly in the indicator up to a certain point. It gave the pressure of steam upon the piston throughout the stroke, and it was never intended to show what was going on inside the boiler or in the screw shaft. It told everything from the boiler to the condenser. It showed if there was a stricture in the pipe leading from the boiler to the cylinder, if the throttle-valve was too small, if the steam was wire-drawn, if the piston was leaking, if the cylinder was honeycombed or flat-sided, if the valves had too much lap or lead, and it told the state of the condenser. He thought, therefore, that the little instrument gave a very good account of the work done in the cylinder by the fuel consumed; and if it accomplished so much, it ought not to have been passed over by a reference to what it could not do, and to what it was never intended to do. With regard to the surface condenser, he had always felt great pleasure in giving credit to those who really deserved it; and while he gave all praise to Messrs. Randolph and Elder who had brought to bear on the subject an immense amount of talent and ingenuity, it ought not to be forgotten that had it not been for the surface condenser such high-pressure steam would not now be used as was commonly employed. He therefore

thought that the name of Mr. Samuel Hall might have been brought more prominently before the Institution in connection with that subject. Mr. Hall had worked engines at 115 lbs. pressure, the consumption of coal being 1·50 lb. per indicated HP. per hour. He had documents in his possession from a person who had seen the vessel running between Glasgow and Liverpool, which it continued to do for several months. A difficulty arose with the vessel, as difficulties had arisen with other ships treated in a similar way. A steam pressure of 115 lbs. had never been worked for any length of time successfully with marine engines. Where vessels had been built with steam pressed as high as that point, they had after a short period of work been compelled to fall back to a pressure of 75 or 80 lbs. Some doubt had been expressed with regard to the single engine. He had made many of those engines, not only for Mr. Alfred Holt but for Messrs. Holt of Liverpool, and others, and he could say that with a fly-wheel attached to the engine, on going into the engine-room of the ship one could see no difference between their working and the working of a double cylinder engine. Reference had been made to steam jacketing, but no allusion had been made to a much more important matter—that of reducing the steam to a low temperature. He believed that there was an immense loss by expanding steam at too low a temperature. The internal radiation or conduction with a low temperature involved an enormous loss, and it was better to work at a little higher temperature at the lower end of the stroke.

Mr. James Bailey, C.B., observed, through the Secretary, that the Author had suggested the use of higher pressures of steam as the means to obtain more economical results. From a return made to an order of the House of Lords in 1874, it appeared that the frequent renewal of marine boilers was an important item of expenditure, as well as a cause of great weakness in the practical strength of the British Navy. Amongst a long list of ships mentioned the "Pallas," first completed for sea in 1866, received new boilers in 1871, and the "Research," completed for sea in 1864, received new boilers in 1869; it would thus appear that the life of a marine boiler in the Navy was less than five years. The time occupied, and the expense attending the renewal of boilers, including the removal of old boilers and refitment of the ships to a working state, had not been given, but it must be a very heavy tax on the nation, independent of the ships being non-effective for considerable periods, and the strength of the Navy so much reduced.

During the present financial year, the building of new ships had been deferred to render the funds destined for ship-building available to re-boiler the iron-clads. What he wished to point out was, that with the improved system of steam engineering such as Mr. Perkins had initiated and matured these frequent renewals of boilers were unnecessary, and that the efficiency of the fleet, and its aggressive power, might be much augmented at a less cost than at present. This was accomplished by the use of engines working steam at a higher pressure, by boilers absolutely safe from explosion, and the two combined, by working the high-pressure steam more expansively, performed work on a much smaller consumption of fuel than at present. This system of engines and boilers possessed the following advantages, which increased both the efficiency and economy:—(1) The extremely small consumption of fuel, say 1 lb. of coal per HP. per hour. (2) The almost absolute safety of the boilers from explosion, brought about by the construction of tubes and the distribution of metal to secure strength in the position and form for performing the functions required in a boiler for containing high-pressure steam safely. (3) The duration of the boilers equal to that of the engines and ship they were applied to. (4) The disuse of all oil and grease for lubricating the interior wearing surfaces. (5) The reduction in the weight of the engines and boilers combined, as compared with those in use. In reviewing these features their great economy and industrial bearings would be apparent. (1) The consumption of fuel in steam vessels might be practically regarded as the index of their commercial value, and in ships of war as that of their aggressive power. In vessels of commerce, each ton of coal burnt should be valued as the cost of the same ton plus the loss of so much paying cargo as the ton occupies; whilst in vessels of war, to the cost of the coal may be added the gradual disablement of the vessel as the supply of fuel is exhausted. The reduction of the consumption of fuel in steamers by one-half, still maintaining the same actual HP., meant also that they could do a double journey, or keep the sea twice as long; this latter advantage was of vital importance to ships of war, and was of no slight importance to the mercantile fleet now trading to India, and other distant places. The best-constructed compound engines used, say, 2 lbs. of coal per HP., whilst Mr. Perkins's system used only 1 lb. It might be observed that the reduction in the consumption of fuel brought a corresponding reduction in the staff of stokers and coal-trimmers, and by means of the boilers being encased with a non-conducting

material, the engine-room and stoke-hole were maintained at a lower temperature—a matter of practical importance in the Red Sea and other tropical latitudes. (2) He had been fortunate enough to see a Perkins boiler burst from being allowed to get short of water, whilst the high-pressure steam (500 lbs. per square inch) was on, with no worse result than the escape of the steam up the funnel. For vessels of war, liable to receive a shot in their boilers during an engagement, this quality was very valuable; and in case of damage, as the parts were interchangeable, repairs might be effected afloat, or at the nearest port or naval reserve of stores. (3) The boilers were charged with rain or drinking water, and this, after being converted and used as steam, was recondensed and reused. If all the joints and valves were theoretically perfect, the same water would last for ever, as it was only the loss caused by these imperfections which had to be made up. In practical work, the quantity required had been found so small as to be easily provided for. This water being comparatively free from solid matter, and small in quantity, created no deposit or crust inside the boilers, they never became burnt, and the wear was so slow and gradual, that one, when taken to pieces, after twelve or thirteen years' constant work, by the Admiralty Boiler Committee, showed no appreciable sign of decay. By this system, the boilers could be made equally lasting with the engines and ship. This feature alone deserved attention, especially in the working of sea-going vessels, the boilers of which were so frequently renewed at great cost, entailing lengthy demurrage in the case of the merchant navy, and for the time rendering ships non-effective, and occasioning loss of strength to the nation in the cases of ships of war. (4) One of the requirements to overcome the friction in the cylinders, when dealing with high-pressure steam, was attained by the discovery of the Perkins patent piston metal. At even moderately high pressures it was found that the cylinders were cut, and that the wearing surfaces of the valves and slide faces were kept true with difficulty. These drawbacks had been thoroughly mastered by the new metal, bringing with it the further benefit of requiring no artificial lubricant. The cost of the oil and grease was thus saved, and the frequent inconveniences caused by their residues in cylinders, pumps, and condensers were thus avoided. It might be justly stated that, by the use of this metal, one of the most material hindrances in the way of the successful application of steam at higher pressures than heretofore, had been overcome. (5) The cost of making engines on Mr. Perkins's system did not, he believed, exceed that of any other well-manufactured engine,

actual working power being taken as the criterion; and the weight and space required by the engine and boiler were less than of other engines in general use.

Mr. WALTER BROCK, through the Secretary, observed that, of all the points worthy of discussion, suggested by the Paper, by far the most important, in his opinion, was the issue raised as to the effect of "Governmental interference with steamships on the plea of public safety." He regretted, therefore, the remarks made by the President, deprecating the discussion of the action of the Board of Trade in this matter. This question was of vital importance to the steam shipping interest of the country. It was believed that Government interference, while in some respects beneficial, had in the main, and especially in its recent developments, been prejudicial and obstructive. Hence, it would appear to be in the highest degree desirable that this subject should meet with the fullest consideration and discussion from the members of the Institution. Attention had been specially called to what Mr. Traill referred to as "the book," in regard to which the Author justly remarked that it "will repay perusal and be found not unamusing." This "Book of Instructions to Surveyors of Ships," in the part devoted to steam machinery, contained detail rules in accordance with which certain parts of the said machinery must be constructed. Apart altogether from the question whether these rules were correct or not (and that they were not he, in conjunction with others, had endeavoured to show in another place), it must be evident that if the Board of Trade persisted in their present policy, it must necessarily lead to a large and indefinite multiplication of the rules, so as to embrace, ultimately, all details of steam machinery on board ship. Dealing, as they did at present, with only a few out of the many details of machinery, their position was capricious and illogical, because no sufficient reason could be assigned why certain parts should be specially legislated for to the exclusion of others equally important. The necessary outcome, therefore, of a persistence in the present line of action must be to make a Government department the responsible designer of the engines and boilers of the mercantile marine. The mere prospect of such a possibility, with its attendant consequences, appeared to him amply sufficient to justify the Author's suggestion that the Institution would add to the services it had rendered to engineering progress by protesting. Mr. Traill had given what he called facts as to the bursting of two boilers by hydraulic pressure; but, as far as he recollected, the only inference which he drew from them was a corroboration of the rule

given in the "Book of Instructions" for calculating the strength of boilers. Mr. Traill seemed to have overlooked one aspect of these experiments, which he took to be the most important, viz., that they showed what was the actual margin of safety possessed by these boilers during the time they were at work. He believed he was acquainted with all the particulars of one of the cases cited by Mr. Traill, and what was said above at least applied to it. It was the case of the boiler which burst at a pressure of 230 lbs. per square inch. This boiler had been constructed for a working pressure of 60 lbs., and, as a matter of fact, worked for some six or more years at that pressure. It would be admitted by all engineers acquainted with that experiment, that the boiler was not in any way weakened by corrosion, and that, in fact, if it had been subjected to a pressure of 230 lbs. per square inch when new it would have burst then. The conclusion from this was that here, at all events, was one example of a boiler working with perfect safety for a number of years with a factor of safety less than 4. The Board of Trade required a nominal factor of safety of 7 and upwards for boilers as usually constructed. The "Book of Instructions," however, assumed a strength of iron considerably in excess of what was usually found in practice, and it was probable, therefore, that the real factor of safety of boilers constructed according to the rules was not more than from 6 to $6\frac{1}{2}$. It was submitted that such a factor of safety was unnecessarily high, and might be considerably reduced, with great advantage. It would then become possible, with such a modified factor, and the use of the superior steel now to be obtained, to employ much higher pressures, and that with perfect safety, even in boilers of the present type. A curious illustration of the illogical position of the Board of Trade was to be found in a consideration of the elaborate instructions given for the construction of new boilers, as contrasted with the absence of any attempt to guide surveyors in the much more difficult question of the treatment of boilers that had been years at work, and as to the pressure to be allowed for them. In fact, the Book of Instructions, in regard to this very important question, merely remarked that, "In the case of old boilers, the surveyors must use their own judgment as to the necessary pressure to be applied." Now it appeared to him that the Board of Trade must either legislate on this matter, or leave it, as at present, to the discretion of the surveyors, who, if competent to deal satisfactorily with this important question, could surely be trusted in all other matters of a survey. He was aware that an objection had been

raised to leaving a survey in the hands of a surveyor, without detailed instructions for his guidance, because it would be likely to lead to a non-uniformity of practice at different ports. It appeared to him that this objection was of little consequence, because, with a competent staff of surveyors, it might very well be made a rule that a vessel passed originally by one surveyor should not, in matters of design and arrangement, be amenable to survey by another, but that the subject-matter of all other surveys should be confined to the effects of tear and wear on the material. He believed also that much trouble and annoyance might be avoided as to boilers by abandoning all rules and trusting entirely to a hydraulic test. It was submitted that, if a boiler stood a certain hydraulic pressure satisfactorily, it should be accepted as evidence that it was capable of working at one-half that pressure for twelve months, and the surveyor should grant a declaration accordingly. The engineering profession of the country could certainly be trusted to construct machinery without being held in leading strings by the Board of Trade, and, as regarded boilers, all reasonable requirements as to public safety would be amply provided for by the periodical testing above referred to. This, at least, was his opinion, and he submitted it as a point on which the varied and extensive experience of members of the Institution would be most valuable. The whole subject of Government interference was a large one, and the full discussion of even one aspect of it was quite beyond the limits of a communication of this kind. He would only then, in conclusion, remark that there was a widely diffused feeling of dissatisfaction among engineers and shipowners in regard to their present relations with the Board of Trade, rendering as they did any attempt at progress, involving deviations from the beaten tract, exceedingly difficult, and there was an utter want of confidence in the professional advice under which this highly unsatisfactory state of matters has been produced and maintained.

Mr. E. De Rusett remarked, through the Secretary, that the Author had made a statement to the effect that the indicator as an instrument to find out faults was of considerable value; but that its results as a gauge of the propulsion imparted to a ship were often questionable. With these remarks he fully concurred, and would add, that by employing the indicated HP. as a divisor into the coal consumed per hour, a false impression might be conveyed of the comparative economy of engines, when applied for comparison with those of a different type, or where there was a great disparity in the relation of diameter of cylinders to stroke. That

this view was correct he would endeavour to show by reference to the following table of results:—

No. of Example.	Name of Vessel.	Type of Engines, all Direct Acting.	Dimensions of Cylinders.		Ratio of Stroke to Mean Diameter of Cylinder.	Trial Results.		
			Diameter.	Stroke.		Displacement.	Indicated HP.	Speed per Hour.
a.	*b.*	*c.*	*d.*	*e.*	*f.*	*g.*	*h.*	*i.*
			Inches.	Inches.		Tons.		Knots.
1	Ceylon	Simple	72	36	0·500	2,983	2,054	13·340
2	„	4-cylinder compound	48 and 96	36	0·500	3,025	2,542	13·955
3	Poonah	Simple	76	39	0·513	3,156	2,550	13·853
4	„	2-cylinder compound	56 and 97	54	0·706	3,970	2,590	13·953
5	Indus.	2- „ „	56 and 97	48	0·627	4,440	2,368	13·670

By a simple analysis of this table it would be seen, firstly, in the results obtained by the "Ceylon's" former simple engines (1), as compared to the work done by her present four-cylinder compound engines (2). The latter type required 488 indicated HP. more than the former to drive an extra 42 tons displacement $\frac{6}{10}$ of a knot faster; but 170 indicated HP. would have been ample, other conditions being the same. Secondly, by comparing the power indicated by the simple direct-acting engines of the "Poonah" before lengthening (3), and that developed by the compound engines, after lengthening (4), the discrepancy was very marked. The power being only 40 HP. more in the latter trials, although there was an increase of 814 tons in displacement, and $\frac{1}{10}$ of a knot in speed. The indicated HP. to produce these results on the basis of those obtained with the simple engines would be about 3,036 or 446 more than that actually required on trial. Thirdly, in the instance afforded by the "Ceylon" (2), and "Indus" (5), the want of uniformity in indicated power was still more apparent. The two-cylindered compound engines of the "Indus," with 174 less indicated HP., drove 1,415 tons more displacement than did the "Ceylon's" four-cylinder compound engines, but at a reduced speed of nearly $\frac{3}{10}$ knot. Reducing these elements of displacement and speed to equal terms, the indicated power required to drive the "Indus's" displacement at "Ceylon's" speed would be 3,086 HP., or 718 more than actually sufficed. The Admiralty formula of $\frac{V^3 \times D^{\frac{2}{3}}}{I.\ HP.}$ had been employed

in each of the above calculations, as it was at present more generally accepted.

Similar instances of the unreliable value of indicated HP. as "a gauge of the propulsion imparted to a ship" were not by any means rare, and this he had observed nearly nine years ago, when investigating the comparative economy of simple and compound marine engines. He was then led to frame a formula $\frac{V^2 \times D^{\frac{2}{3}}}{C}$, when endeavouring to reduce the elements of speed and displacement to as nearly as possible the same terms. His observations extended in some instances over a series of years, so that the other elements, of weather, quality of coal, and the state of the ship's bottom, would be practically common to all, and so neutralised in such an investigation. V^2 had been adopted because the coal consumed per mile was taken as a divisor instead of indicated HP. He had ever since then adopted for this purpose the coal consumed either in lbs. per mile or tons per day; the power of V changing according to circumstances. In a Paper on lengthening the "Poonah," read by him before the Institution of Naval Architects during the present year, the formula used was $\frac{V\ 2{\cdot}3 \times D^{\frac{2}{3}}}{C}$, and where C = tons net coal consumed per day. The reason for changing the power of V^3 to $V^{2{\cdot}3}$ was there given.

The reasons for such discrepancies in indicated power might be looked for in the instrument employed, size and lead of indicator pipes, and also largely, he thought, in the varying ratio of stroke to diameter of cylinders. Examples of this might be observed in the table. Compare these ratios in Examples 3 and 4, also 2 and 5, column *f*, in each of which when the ratio of the stroke to the diameter of the cylinder approached more nearly to equality, the indicated HP. had produced a much higher propelling effect, as might be clearly seen by reference to the preceding analysis. These facts and deductions coincided with the Author's observations in advocating long-stroke engines, and in the condemnation of "cheese shaped" cylinders. He repeated that these objections to the use of the indicated power were only meant to apply where used as a means of comparison between engines of dissimilar type or those in which there was much disparity in the ratios of the stroke to the diameter of the cylinders.

He would now call attention to what the Author observed in reference to companies having postal subsidies. In refutation of his statement that "Government money was used to crush com-

petitors, and as a matter of fact did much to postpone all outside improvement in steam carriage at sea," besides other observations to the same effect, he might mention as an historic fact that the Peninsular and Oriental Company built the "Pasha," an iron paddle-wheel vessel, as early as 1843, or nine years prior to the date from which the Author commenced his review of the progress of steam shipping, and that this company had built and completed by July 1852 fifteen iron paddle and five iron screw steamers, and they had also other nine iron screw steamers building and fitting out by December of the same year. They had moreover increased their fleet by eight iron screw steamers by December 1853, and among these the far-famed "Himalaya." Of the entire fleet of this company to December 1852, comprising twenty-six ships in full work and twelve building or fitting out, there were:—

—	Completed.			Building.		Total.
	Dates.	No.	Tonnage.	No.	Tonnage.	
Wood paddle vessels	From 1836 to 1843	8	10,325	3	1,858	11
Iron „ „	„ 1845 „ 1850	13	14,997	..	..	13
„ screw. . .	„ 1851 „ 1852	5	4,293	9	17,777	14
Totals . . .	..	26	29,615	12	19,635	38

This list excluded two iron paddle-wheel vessels lost; one of which, as already stated, had been built in 1843. By these figures it would be seen that two of the three great changes of construction defined by the Author as having rendered possible the extension of steam shipping, viz., the screw and iron vessel, had received at the hands of a postal subsidised company, "that firm unhesitating acceptance which is a necessary prelude to general adoption;" and especially when it was known that this company had not laid down a single wooden vessel since 1843, except the three building in 1852, which were built of wood and copper-sheathed, simply because they were to be employed on a station where no graving docks were at that time available.

In the next place he would demonstrate the part subsidised companies had taken in the advancement of the third "great change," viz., the adoption of the compound engine. Contrary to the Author's assertion they had been among the first to adopt them and to extend their use. By reference to a list of compound engines kindly furnished him by Messrs. Randolph and Elder,

he noticed that that firm built forty-eight pairs of engines of this type from 1855 to November 1866, consisting of eighteen paddle and thirty screw engines. Of these the second and third pairs were for the Pacific Steam Navigation Company; and that the total collective nominal HP. amounted to 9,190, of which 6,620 or 72 per cent. were for subsidised companies, viz., the Pacific, African, and Panama and New Zealand lines. As regarded the four-cylinder type of compound engines alluded to by the Author as "an excellent engine," and as having been "exclusively employed in the boats of the White Star Line," the Peninsular and Oriental Company had adopted them in the "Mooltan" in March 1861, and she was followed by nine other vessels also fitted with this type of engine to April 1866, when they abandoned this form, and preference was given to the two-cylinder type, such as was now so satisfactorily employed in the propulsion of the largest steamers. At the present time the whole of their working fleet was propelled by compound engines.

With these facts it could not be said, that with all subsidised companies, "science, economy, thrift, all went for nothing, or that such companies have caused great waste, weakened steamboat enterprise as a whole, and left those who received them with fleets and habits unfitted for the race of open competition." The latter part of this quotation from the Paper might be answered by reference to the well-known immunity from losses at sea, both of ships, passengers, and mails, which had been enjoyed by at least two of the great companies—the Cunard and Peninsular and Oriental—the latter not having lost a vessel since the "Rangoon" in 1871, although their fleet have traversed more than 10,000,000 miles, in most intricate waters since that date; and at the present time the whole of their fleet employed in the Mail service, consisting of over 110,000 tons register, was constructed of iron, fitted with the compound engine and screw propeller.

Sir C. A. HARTLEY observed, through the Secretary, that having lived a great deal abroad for the last twenty-two years his attention, as a civil engineer, had naturally been frequently directed to the progress of steam shipping in foreign ports. His chief experience had been with the Black Sea ports, especially with the ports of the Lower Danube. With reference to the latter, he had prepared a note of the clearances of shipping from the Sulina Mouth in 1865, as compared with 1876. The year 1865 was a fair average one for the Danube trade, before the deepening operations of the European Commission of the Danube had been fully developed. In 1865, only one hundred and eighteen steamers

of all nations, of an aggregate of 31,545 registered tons, traded to the Danube. In 1876, six hundred and ninety-three steamers of all nations cleared from the Sulina Mouth, with an aggregate tonnage of 552,340. In 1865, the steamers, which only averaged 267 tons each, bore a proportion of but 7 per cent. of the total tonnage of the Lower Danube, which that year amounted to 410,684 tons. In 1876, the steamers, which averaged 800 tons each, bore a proportion of 74 per cent. of the total tonnage, which last year reached 748,363 tons. The increased tonnage and number of British steamers trading to the Danube, as compared with vessels of foreign nations, was remarkably exemplified by the following figures. In 1865, Great Britain stood only third on the tonnage list, her share, including both steamers and sailing vessels, being but 15 per cent. of the total tonnage; whereas in 1876, of the six hundred and ninety-three steamers which left the river, five hundred and twenty-one, of an aggregate of 445,000 tons, or 60 per cent. of the total trade, were British. Moreover, in the same year the number of English sailing vessels which traded to the Danube had dwindled down to twenty-six, having an aggregate of only 7,450 tons, or less than 2 per cent. of the tonnage of the English steamers. This striking example of the advance of steam navigation over sailing vessels seemed confirmatory of the Author's assertion, "that, broadly stated, British carriage by sea during the last quarter of a century has been transferred from sailing vessels to steamers." He considered, however, that the instance just quoted of the Danube trade did not prove the rule, and that, so long as the chief bulk of the ocean freight of the world continued, as at present, to be carried by sailing vessels, it could not with propriety be said that they had already been superseded by steamers in the carrying trade. Statistics showed that since 1862, although there had been a considerable reduction in the number of British sailing vessels engaged in the foreign trade (from seven thousand and ninety-five to five thousand three hundred and eighty-seven) there had been no diminution, but the contrary, in their total carrying capacity, which in 1862 was 2,993,696 tons, and in 1876 3,234,200 tons. On the other hand, the increase in the total carrying capacity of British steamers engaged in the foreign trade during the same period had been nearly 500 per cent.; but even with this immense increase—from five hundred and ten steamers with a tonnage of 328,310 in 1862 to one thousand four hundred and sixty-seven steamers with a tonnage of 1,489,264 in 1876—the aggregate tonnage of British foreign-going steamers was not yet equal to one-half that of

British sailing ships. It was worthy of remark, as an evidence of the greatly increased growth of late years in the carrying capacity of British vessels, sailing as well as steam, that whilst the average tonnage of steamers was only 600 in 1862, it had increased to 1,000 in 1876; and that whilst the average tonnage of sailing ships was only 422 in 1862, it had increased to 644 in 1876. Taking into account the total tonnage of British sailing vessels and steamers—river steamers excepted—engaged in both the foreign and home trade, it appeared by the following abstract from the Annual Parliamentary Navigation Returns that whilst the aggregate tonnage of steamers had increased 405 per cent. from 1862 to 1876, there had also been a slight increase in the same period in the tonnage of sailing vessels:—

Date.	Sailing Vessels engaged in the Foreign and Home Trade.		Steamers engaged in the Foreign and Home Trade.		Total.	
	Number.	Tonnage.	Number.	Tonnage.	Number.	Tonnage.
1862	19,059	4,011,501	1,033	461,793	20,092	4,473,294
1876	17,228	4,126,058	3,121	1,870,094	20,349	5,996,152

From Sir L. Mallet's "Statement of the Trade of British India for the five years 1871–72 to 1875–76," it appeared that, notwithstanding the immense impetus given to steam shipping by the opening of the Suez Canal, only 41 per cent. of the entire British trade with India was carried in 1876 by steam vessels. And yet, as the following statistics showed, the tonnage of steamers trading to and from India by the Suez Canal had increased threefold from 1871 to 1876:—

——	Entered.		Cleared.	
	Number.	Tons.	Number.	Tons.
1871–72	212	234,782	208	229,416
1872–73	259	318,300	273	308,524
1873–74	317	434,152	306	382,375
1874–75	413	575,892	409	558,076
1875–76	483	704,325	522	735,945

As an example of the value in a commercial point of view of the great Empire in the East, it might be mentioned that in 1876 the tonnage of British Indian sailing and steam ships trading to India

was 2,188,590, or 436 per cent. more than that of all foreign nations employed in the same trade.

He had been favoured by Sir John Stokes, K.C.B., Assoc. Inst. C.E., with the following statement (see next page) of the total traffic through the Suez Canal from its opening in 1869 to the 31st of December, 1876, distinguishing British steamers from steamers of other nations.

He would now briefly refer to the great preponderance of British ocean steam shipping to that of all other nations put together. Excluding river steamers, the commercial steam fleet of England was equal in round numbers to more than double that of the United States, to five times that of France and Germany combined, and to ten times that of Holland, Italy, Norway, and Denmark combined. With regard to the United States, Consul-General Archibald, of New York, reported to the Foreign Office that in 1860 nearly two-thirds of the foreign importations were brought in American ships, whereas during 1876, not more than one-fourth of the imports came in under the American flag. Mr. Archibald gave the following particulars relative to the number and tonnage of British vessels arriving at the port of New York in 1868 and 1876 :—

—	Sailing Ships.		Steamers.		Total.	
	Number.	Tonnage.	Number.	Tonnage.	Number.	Tonnage.
1868	1,690	543,256	312	702,865	2,002	1,246,121
1876	1,231	561,503	590	1,588,113	1,821	2,149,616

This comparative statement showed no diminution in the tonnage of sailing vessels, and a marked increase in the size of both sailing ships and steamers.

Although the Americans had hitherto surpassed all other nations in the building and equipment of fast and commodious river steamers, neither America nor any other nation had yet built steamships so well adapted for ocean navigation as those of Great Britain. Hence one great cause of the unquestioned supremacy of our mercantile steam marine. There were many other causes, however, which had led to this result, and among them might be mentioned: the vastness of our possessions in every quarter of the globe, free trade, an abundance of the requisite materials for the building and working of steamers, viz., iron and coal, the transport of the latter as cargo being also productive of profitable

SUEZ CANAL.

TRAFFIC FROM the DATE of OPENING to the 31st of DECEMBER, 1876.

Year.	British.			Other Nationalities.			Totals.		
	Number of Ships.	Net Tonnage.	Gross Tonnage.	Number of Ships.	Net Tonnage.	Gross Tonnage.	Number of Ships.	Net Tonnage.	Gross Tonnage.
1869 (36 days).	9	6,286	8,980[1]	1	290	435	10	6,576	9,415
1870. . . .	314	289,234	433,851[1]	172	146,677	221,064[1]	486	435,911	654,915
1871. . . .	502	546,453	819,679[1]	203	215,014	322,521[1]	705	761,467	1,142,200
1872. . . .	761	835,490[1]	1,253,235	321	325,253[1]	491,246	1,082	1,160,743	1,744,481
1873. . . .	813	999,861[1]	1,499,791	360	367,906[1]	585,281	1,173	1,367,767	2,085,072
1874. . . .	898	1,198,330[1]	1,797,494	366	433,320[1]	626,178	1,264	1,631,650	2,423,672
1875. . . .	1,061	1,454,258[1]	2,181,387	433	555,726[1]	759,321	1,494	2,009,984	2,940,708
1876. . . .	1,090	1,579,572	2,343,523	367	517,199	728,584	1,457	2,096,771	3,072,107

[1] Approximate.

outward freights; and last, not least, the advantage of having shipowners who knew the value of time, and ship captains whose energy, pluck, and seamanlike qualities so admirably fitted them, as a rule, for the important posts they held. The latter point was well sustained and corroborated in a communication which had been recently forwarded to the Foreign Office by Consul Clipperton, of Nantes.

In 1876, the total registered number and tonnage of all sailing and steam vessels belonging to the British empire were thirty-two thousand three hundred and seventeen sailing vessels, of 5,814,276 tons, and five thousand three hundred and sixty-three steamers of 2,150,302 tons, or together thirty-seven thousand six hundred and eighty vessels of 7,964,578 tons. In this return all the British possessions were included, and thirteen thousand five hundred and twenty-eight sailing vessels, of 404,664 tons, and seventeen hundred and sixty-one steamers, of 38,815 tons. Between 1872 and 1876 there had been an increase of 241,086 tons in the tonnage of sailing vessels, and of 509,663 tons in the tonnage of steamers. The estimated number of the crews (exclusive of captains) for all registered vessels belonging to the British empire in 1876 was 348,959.

But to return to the Black Sea ports. The total clearances of vessels of all nations from the Russian ports of the Black Sea and Sea of Azov, per year, during the three years ending 1876, were about 1,500,000 tons, of which 30 per cent. were British. He had not been able to ascertain the proportion of steamers as compared with sailing vessels, but her Majesty's Consuls of the Black Sea and Azov ports were of opinion that steamships continued to gain ascendency over sailing vessels. He believed that this ascendency would be still more marked as the deepening operations, undertaken by the Russians of late years in their Black Sea and Azov harbours, became more fully developed, especially after the deepening, which was completed only last year, of 5 feet, viz., from 13 feet to 18 feet, over a channel 250 feet wide, through the shoals of the Straits of Kertch from sea to sea.

The remarkable increase in the tonnage of steamships trading to the Danube was principally due to the deepening of the lower part of the river and of one of its mouths; and a consideration of this fact led him to conclude that, in addition to the three elements which the Author had represented as being the cause of the great progress of steam shipping up to this time, viz., the screw propeller, the iron vessel, and the compound engine, there was yet another element of value to be taken into account

—that of the increased depth of water which had been obtained during the last quarter of a century in harbours and rivers at home and abroad; for, as the Author had already observed, to work properly and to compete successfully with sailing vessels, steamers must have great depth of hold; consequently, they require a great depth of water in which to float. In this department of improvement hydrotechnical engineers had still a wide field of usefulness before them, no whit inferior in importance, he held, to the work which had yet to be accomplished by the great mechanical engineers of the day, whose chief aim was how to improve to the utmost possible extent the economical working of our commercial steam fleet present and to come.

With regard to the practical working of the Board of Trade regulations abroad, he had only to remark that the result of his personal observations, as far as the Black Sea ports were concerned, was that the working of the Merchant Shipping Act of 1875 had undoubtedly checked in a great measure the overloading of steamers and the bad stowage of grain; practices which previous to the passing of the said Act had been so perilous to human life, and so injurious to the best interests of trade.

It was stated by the Author "that the one who had almost alone benefited by the change was the consumer." Now he had the conviction that the whole of the civilised world had gained by the change, *i.e.* the late rapid strides of steam navigation, excepting perhaps a few unfortunate owners of sailing vessels, who might have been swamped from time to time by their powerful iron and steam competitors for the trade of the seas. It could not be supposed that steamship owners could always be gainers, when their steamers, after (as was too often the case) an outward-bound voyage in ballast only, actually carried cargo at times over thousands of miles at a rate of less than $\frac{1}{12}d.$ per ton per mile; yet even grain was carried at this low rate from the Black Sea ports to England, when freights fell, as they did in July 1876 for instance, from the Danube to England, to 4*s.* 6*d.* per quarter. There were seasons, however, when they reached, as in November following, 9*s.* 3*d.* per quarter, and at such a rate the profit must be great. His own experience was that owners of steamers, as a body, had been as fortunate on the whole in their speculations as their brother capitalists, who had invested their money in apparently less risky undertakings. The chief result of the rapid growth of the transport of goods over sea by steam power had undoubtedly been to lower the rate of freight from port to port; and producers, therefore, whether they lived on the banks

of the Ganges, the Mississippi, the Danube, the Vistula, or on the shores of the great American lakes, participated largely in the benefit of such lowered rates; for the value of, say, a quarter of wheat at any of these localities was the price paid in the British markets, less the cost of transport. Thus producers abroad had been benefited as well as consumers at home by the great progress of steam shipping during the last quarter of a century; and its still greater development in the future would, he felt sure, continue to prove a blessing to all mankind.

Mr. Douglas Hebson observed, through the Secretary, that while he concurred with the Author, who had himself done so much towards it, in what he had said of the progress of steam shipping during the last quarter of a century, he did not quite agree with him that the introduction of the compound engine had done more than the screw propeller or iron ship. The economy in fuel of late years had been due chiefly to the use of higher pressures of steam, and the Author himself seemed to think that it was not impossible that the single cylinder might yet be preferred. Theoretically, there was no doubt that the steam could be used economically in one cylinder as well as in the compound. However, the compound engines of the present day were thoroughly efficient, and did not involve any such complexity as the name suggested.

The Author had referred to the good service rendered by Mr. Elder in the introduction of the compound engine for steamships in this country. It might be interesting to the Institution to learn that Messrs. Alexander, of Barcelona, fitted a steamer with compound engines in Spain in the year 1854, and that they had continued to make these engines ever since. He had had under his care here four steamers fitted by them with compound engines of very good construction, entirely of their own design and manufacture.

In his opinion, by far the most important part of the Paper was that which referred to the action of the Board of Trade in connection with steam shipping. But for this, he should take a much more hopeful view of further progress in the future than the Author did; but when he remembered that in such a simple matter as the use of spring-loaded safety valves for steamships, it required repeated applications by different persons, extending over a period of from ten to fifteen years, before their permission could be obtained to use them instead of weights, which were unsuitable when a ship was rolling at sea, he felt apprehensive that other countries would take the lead in the race of improvement. He had before him a copy of the Board of Trade

instructions to surveyors, and he could not too strongly support the Author's wish that the Institution should take an active interest in the matter.

None but those who had experienced it could have any idea of the minute and injudicious extent to which steamship owners and engineers were controlled by the Board of Trade.

Mr. MACKENZIE remarked, through the Secretary, that, in his opinion, the rapid decay of boilers, when used with the distilled water from surface condensers, was probably to a considerable degree due to slow galvanic action going on between the boilers and the brass tubes generally used in surface condensers, which action would be kept up by the constant circulation of steam and feed-water between the two. He had recently seen a small wrought-iron pipe which had been corroded through, and required renewal in a comparatively short time. This pipe conveyed condensed water from a copper steam pipe. Similar wrought-iron pipes, taking condensed water from iron steam pipes connected to the same boilers showed no signs of rapid corrosion. There did not seem to be any reason why iron or steel tubes should not be used in surface condensers, as they answered perfectly under more unfavourable circumstances in boilers used with salt water. The Perkins engine had iron tubes in the surface condensers, and to these was probably due a part of the durability of the boilers which had been noticed by Admiral Selwyn.

Mr. F. C. MARSHALL remarked, through the Secretary, that to the compound engine, and its introduction to the mercantile marine, the Author attributed a large measure of the progress which steam shipping had made during the last quarter of a century; and principally because by its introduction the fuel burnt on board steamships had been reduced from the old standard of 4 lbs. and 5½ lbs., to 2 and 2½ lbs. per indicated HP., thus enabling the shipowner to undertake longer voyages, and so widen the field of his operations. The Author further proceeded to say that he did not look, nor hope, for more than a further reduction of 20 per cent. during the next twenty-five years, so bringing the consumption of steam engines on board ship to 1·8 lb. per indicated HP. It did not appear desirable, or a right thing, that such an expression of opinion, coming as it did from a most experienced marine engineer and large shipowner, should pass without remark. Marine engines had been made, and had afterwards worked on Mediterranean voyages on 1½ lb. of fuel per indicated HP., and on their trial trips realised the limit of 1·05 lb. per indicated HP. At this moment he knew of many steam vessels which were regularly

worked on long voyages on 1·7 to 1·75 lb. of fuel per indicated HP. It was in order that the statement of the ultimate result mentioned in the Paper as probably attainable in the future might not go forth as the unchallenged opinion of the members of the Institution, that he ventured to make these remarks. The fact named, that engines at sea had been worked, even on occasion, for hours together on a consumption of 1·05 lb. of fuel per indicated HP., and although they failed to maintain the modified result of 1·5 lb. for more than a few voyages, he held, should lead all persons interested in scientific and commercial progress to seek to make such result permanent. The difficulties in the cases he alluded to were, he believed, entirely of a practical or structural character, such as recent experiences had to some extent removed, and with the materials now available, which were not then, might be still further overcome. In consideration of these facts, it did not seem unreasonable to look for a 50 per cent. reduction, instead of the 20 per cent. on the present performances mentioned by the Author of the Paper. As the result of experience, he ventured to question the statement that there was even a speculative probability of the single-cylinder engine ever forcing aside the compound form. So long as it was found that increased economy lay in the direction of higher pressures, the conservation of the heat of the steam was of vital importance; and the wide range of temperature existing between the initial steam and the surfaces of cylinder, cover, and pistons, which had been exposed during the exhaust to the temperature of the condenser, must ever prove a hindrance to a return to a system involving such a positive and decided loss. The following was a statement showing the working of two steamers, identical in every respect, both started in the same year, and both engaged in similar trade; the one, the "King Coal," had two cylinders 38 inches in diameter, 30 inches length of stroke, and worked simple expansion with 40 lbs. steam; the other, the "Glenmanna," had cylinders 25 and 48 inches in diameter, 30 inches length of stroke, compound engines, with a steam pressure of 60 lbs. The statement showed the comparative running on the voyages to Hamburg and back, and the relative consumption of fuel and of water.

	"King Coal."	"Glenmanna."
Vessels:—		
Length	209 feet.	209·4 feet.
Breadth	28 „	28·2 „
Depth	14·5 „	14·4 „
Tonnage under deck .	647 tons.	650 tons.
Dead weight carried .	1,000 „	1,020 „

	"King Coal."	"Glenmanna."
Engines :—		
Nominal HP. . . .	90 HP.	90 HP.
Pressure	40 lbs.	60 lbs.
Diameter of cylinders .	38 inches.	25 and 48 inches.
Length of stroke . .	30 „	30 „
Boilers :—		
Length	10 feet 6 inches.	10 feet.
Diameter	13 „	11 feet 6 inches.
Heating surface . . .	1,974 square feet.	1,484 square feet.
Grate surface . . .	54 „ „	45 „ „
Propeller :—		
Diameter.	12 feet.	12 feet.
Pitch	14 feet mean.	14 feet mean.
Area	36 square feet.	36 square feet.

The average speed of "King Coal's" engines when loaded was 62 revolutions, developing 323 indicated HP. The average speed of "Glenmanna's" engines when loaded was 64 and 65 revolutions, indicating about 360 indicated HP. Both engines were by the same engineers, and the vessels by the same builders. The boilers of both vessels had been at work more than six years. His data were based as follows: In forty-four voyages to Hamburg and back, the "King Coal" consumed, on an average per voyage, 54 tons of coal; the "Glenmanna" 34 tons. He assumed that the quantity of water evaporated in both cases was eight times that of the coal used.

	"King Coal."	"Glenmanna."
Voyages per annum	44	44
Coals per voyage	54 tons.	34 tons.
„ „ annum	2,376 „	1,496 „
„ „ six years	14,256 „	8,976 „
Water evaporated per annum . .	19,008 „	11,968 „
„ „ „ six years . .	114,048 „	71,808 „

The saving in the amount of coal consumed in favour of the "Glenmanna" for the six years was £2,112, taking the value of coal at 8*s.* per ton. The "Glenmanna" would take nine years to use the same quantity of coal and water as had been used in the "King Coal" in six years. The average consumption of coal in the "King Coal" per day was 13½ tons, and in the "Glenmanna" 8½ tons. The last three voyages of the "Glenmanna" were done on 7 tons 11 cwt. 1 qr. 4 lbs. of coal per day. To his mind this showed that, even with the best management, the simple expansion engine could not be made to do the same work with equal economy, and therefore must give way to the compound engine.

As to the best form of compound engine the Author had not

stated his opinion, though the results of his experience on this point would be most valuable to the Institution. The modified form of Woolf engine, which he adopted for all his vessels, merited respect, if on no other ground than that he persistently adhered to it, even for vessels now building, and that he did so after many years' experience of its working on the longest voyages in the world. It occupied somewhat less space in the ship—what percentage of the "propelling power capacity," so called, he thus saved over the ordinary form it would be very interesting and useful to know—it had few working parts; he believed it was no lighter than the ordinary two-cylinder form, and by the aid of steam starting gear, fly-wheel, and a little management on the part of the "human factor" the Author mentioned, was readily started and reversed. But, judging from published statements, and a careful theoretical investigation of the working or behaviour of the steam under this system, it did not give so high economical results as the now common form of two cylinders of different diameters, with a receiver between, working on to cranks at right angles. In his recently published work, Mr. D. K. Clark, M. Inst. C.E.,[1] showed that with the ordinary form of Woolf engine, arranged in principle in the same manner as the Author and the constructors of the engines of the White Star line had adopted, there was a distinct loss of efficiency of from 10 per cent. to 12 per cent.; and that, with the best possible modification of the plan and the most careful management, this loss might be reduced to 5 per cent. over the ordinary form of compound engine. What he had called the ordinary, or receiver compound engine, was so well known as to need no description from him; and it had been so often recently discussed that it was unnecessary to go into its details. It sufficed to say that in its arrangements, whether in the two, three, or four-cylinder form, it afforded scope for large increase in pressures, large powers, long stroke, and great economical efficiency, inasmuch as by careful arrangement of cylinders a maximum of power might be got out of the heat of the steam, before bringing it into contact with the surfaces alternately exposed to the steam and condenser. In the four-cylinder form of engine, with others, he included those of the Woolf system adopted by Messrs. Imray in the White Star line, and which, by the very simple expedient of taking the exhaust of the high-pressure cylinder of one engine into the low-pressure cylinder of the other, instead of into that immediately

[1] *Vide* "A Manual of Rules, Tables, and Data for Mechanical Engineers." 8vo., London 1877, p. 855.

below it, as at present, all the advantages of the receiver plan could be obtained. He had not heard of this ever having been done, and never had an opportunity of doing it himself, but the losses before alluded to as incidental to the Woolf system proper might be avoided by so doing.

The comparative efficiency of the three descriptions of engine, which might be called the simple expansion, the receiver compound, and the Woolf compound, might be put down in terms of lbs. of steam per indicated HP. per hour as follows :—

Simple expansion in single cylinder	21 lbs.	to	30 lbs.	per	indicated	HP.
Receiver compound	15 „	„	18 „	„	„	„
Woolf	18 „	„	20 „	„	„	„

He knew many receiver compounds working at 16 and 17 lbs. per indicated HP. His experience of simple expansion engines gave 23 lbs. as the lowest and 33 lbs. as the highest weight of steam per indicated HP.—a large margin to be overcome before the single cylinder could displace the compound engine.

The Author complained of the rules of the Board of Trade, and more still of the action of its Surveyors. As a manufacturer, he could not indorse his complaints. It was true engineers were now subjected to an amount of inspection they did not like, and had to regulate their proportions by more defined rules than they sometimes thought were either wise or best. Still, he was old enough to remember the time when there was no other rule or guide as to the requirements of the Board of Trade than the whim and caprice of the Surveyor himself, and what was passed by him in one port was condemned the week after by his colleague in another. The rules were issued to remove the evils complained of, and now at least there was uniformity of requirement throughout the country. Again, it could not be denied that prior to the issue of rules, great laxity prevailed, even in the best establishments, in the arranging and proportion of plating, riveting, and staying of boilers, as well as in the workmanship connected with them. "Every man did that which was right in his own eyes," and it was to be feared that the "balance sheet" at the end of the year's work was too much considered in many cases, and led to bad design, bad material, and bad workmanship. The effect of the more careful supervision and enforcement of the rules had been to produce a greater equality of goodness in the workmanship and material. He was not going to say that the views enunciated in the rules were the best possible, nor that they were always necessary or wise; but he could in justice say this, that in every case

where an error had been pointed out, or a modification asked for, more in accordance with the just requirements of any special case, he had always found the officers in the out-ports ready to meet him as far as their powers would allow; and if these did not extend far enough, then an application to the officers in London, fairly and frankly put before them, had always been as fairly and frankly met. The Author was probably right in saying the tendency of the present system was to lead the Board gradually into the position of designer, and to a resistance to novelties and preference for stereotyped forms; but of late, complaint could not be raised that such had been the fact; novelties had been introduced after sufficient trial, and if, as in the case of steel for boilers and ships, the Board required careful tests and trials to be made before giving its official sanction to its use, it seemed to him that the history of steel manufacture in the past—as many builders could testify—both in the case of plates, bars, castings, and forgings, fully justified the caution the Board had exercised. This case of the use of steel was but one instance, many others could be given. The Board of Trade in all its departments was, to a large extent, what the public had made it, by its unceasing and often unreasoning demands; and if the outcome was not quite what shipowners liked, the way to remedy the evil was to grapple with it intelligently, and with due regard to all the interests concerned, and not by mere protesting or scolding on the part of any institution or body, however powerful or important.

Mr. R. E. Middleton observed, through the Secretary, that the discussion on the Paper recalled to his mind a small piece of personal experience illustrative of the steady running of single engines. In June 1871 he made a voyage from New Orleans to New York in the "Emily B. Soudar," an American screw steamer of about 1,000 tons. The engine was a single-cylinder one of the inverted vertical type, and the circulating pumps were worked by a separate horizontal engine. When in the Gulf Stream, off the coast of Florida, one of the tubes in the starboard boiler burst, and the engineers had to give all their attention to plugging it. There was a little sea on, and it was of importance that the engines should not be stopped; he therefore volunteered to take charge of the engines while the repairs were going on. It was impossible to drive the plug while there was any pressure in the boilers, but by watching the gauge in the engine-room closely, and by the help of a lamp held to the clearing cock, seeing that there was no pressure there, enough vapour was kept in the boiler to form a vacuum in the condensers,

and the single engine was worked for five hours without hitch or irregularity.

Mr. REDMAN observed, through the Secretary, that if during the last quarter of a century, carriage by sea had been transferred from sailing to steam vessels, and if profit and comfort were minimised in the process, it would be a sorry view for the British shipowner and traveller if this admitted of no explanation. This kind of broad assertion acted prejudicially; it was not new, and had been used by the opponents of harbour extensions, notably in the case of Dover. He had read a Paper on the 5th of May, 1875, before the Royal United Service Institution, on the Enclosure of Dover Bay,[1] in which he had shown the progressive increase of the commerce of Great Britain. It might be said that in 1850 the steam value as regarded tonnage carried was one-sixth of the whole only, but that it was now more than one-half, and this was exclusive of the Royal Navy, which, if included, would somewhat raise the steam value. When it was considered that in 1850 the aggregate foreign tonnage of the United Kingdon was fourteen millions, and that it was now fifty millions—in other words, that it had more than trebled and nearly quadrupled in twenty-seven years, and that there was a corresponding coasting increase—it was not extraordinary that wrecks, collisions, and fouling of lightships had been multiplied.

Mr. G. B. RENNIE remarked, through the Secretary, that the Author of the Paper had so much practice and experience with the working of what is now a large and powerful line of ocean steamers, that any remarks from him had great value to the owners as well as the constructors of steamships and their machinery. The Author treated the subject so fairly that one could not but agree in the most part with what he said. However, the "three changes of construction" mentioned by him seemed to deserve some further discussion in an engineering point of view. The "three changes of construction" mentioned by the Author as having revolutionised the sailing mercantile fleet of this country to one almost entirely propelled by steam, were: 1st, the screw propeller; 2nd, the iron ship; and 3rd, the compound engine. Of these, the screw propeller was practically the same as when adopted fifteen years previously to the time when the Paper took up the subject; namely, in the "Archimedes" merchant ship in 1839; and in the "Mermaid," afterwards named the "Dwarf," two years later, for naval service, as carried out by the late George and

[1] *Vide* Journal of the Royal United Service Institution, vol. xix., p. 665.

John Rennie: the former being a low speeded ship of $8\frac{1}{2}$ miles per hour, and the latter a fast ship, with a speed of a little more than 12 miles per hour, which was faster than any paddle-wheel ship in the navy at that time. This ship had a length of 8 times her beam, which, according to the Author's statement, was very nearly the proportion now in favour, viz., $7\frac{3}{4}$ times the beam for the length. There was not, therefore, much to be said as far as the screw propeller was concerned, except to regret that the steamship owners did not see the advantages offered and adopt it at an earlier period than they did. 2nd. The iron construction of the hull of the ship had tended most materially to the development of screw propulsion. The screw propeller being applied to the extreme end of the ship, it was difficult to obtain, in a wood construction, sufficiently fine lines combined with the necessary rigidity to resist its constant working and vibration; and this was of perhaps more importance in merchant ships, which were usually worked at nearly full speed; whereas in naval ships it was only done on rare occasions. The iron hull, as usually constructed, was almost the same as in the earliest examples of iron ships, in which the late Mr. John Laird, of Birkenhead, amongst others, took a prominent part. Iron ships are now made considerably heavier than formerly, and in many cases, he was inclined to think, to their detriment. The system of fixed scantlings, in order to take a certain classification for insurance purposes, had rather tended to add material and weight to the ship more than its strength; the size and scantlings having more consideration than the manner of uniting its parts together and the quality of workmanship; this had much improved, however. The longitudinal construction of the framework of a ship had not found much favour with shipowners, but for lightness and strength had many advantages: it was commonly adopted in iron ships for naval purposes; and he believed he was right in saying that Mr. Scott Russell introduced this system, which had been afterwards carried out by him in the "Great Eastern." 3rd. The compound engine, as the Author stated, perhaps more than anything else, has given an impulse to the conversion of the sailing mercantile marine into fast-going steamers. In general terms it might be said, that the same power of engine, by its adoption, consumed half the amount of fuel than formerly was required, and enabled the ship to steam double the distance with the same coal bunk capacity. He submitted a comparative statement of fuel used in different kinds of engines, as mentioned in a Paper read by him at the Institution of Naval Architects in 1871.[1]

[1] *Vide* Transactions of the Institution of Naval Architects, vol. xii., p. 1.

Table 1. The type in ordinary use in merchant ships previously to the adoption of the compound engine was that marked No. 3,

TABLE 1.—COMPARATIVE CONSUMPTION of COAL.

Type of Engine.	Per HP. per Hour.	Tons per Diem.	Days and Hours Steaming with 240 Tons of Coal.
			Days. Hours.
1. Improved compound	2	43	5 14
2. Ordinary type, with surface condensers and super-heaters	3½	75	3 4
3. Ordinary injection	4½	97	2 11
4. High pressure	6	129	1 21

although there were some few engines in use of No. 2 type, and consumed even less than 3½ lbs. of coal per HP. per hour, as there stated, but they were exceptional cases; for example, a paddle-wheel engine of 300 indicated HP. on board a vessel called the "Dijleh," running on the Euphrates in 1866, between Bagdad and Bussorah, had an average consumption varying from 2·4 lbs. to 2·6 lbs. per indicated HP.; the steam in the boilers was only 25 lbs. pressure; the cut-off, by independent expansion, varied from ¼ to ⅓; surface condensers, superheater in the funnel being used, as well as the cylinders being steam jacketed. Now, as to steam jacketing, it would be interesting to the members of the Institution to know on what basis the Author arrived at the conclusion of this arrangement being practically of little use. It was quite contrary to the experience of many engineers. In order to satisfy himself as to its utility or not, he caused to be tried in his factory engine (and great care was taken both as to the indicated HP., coal, and other circumstances), for week by week alternately, with and without steam in the jackets round the cylinders. The results were shown in Table 2 (see next page); the columns marked A being those trials with steam let into the jackets, and those marked B without steam in the jacket; the average saving showed 31 per cent. in favour of A. It was essential, when steam surrounded the cylinder, that all the steam which had been condensed into water should be drawn off regularly, and this, no doubt, was more easily done on land than on board a sea-going ship; but he thought, with proper arrangements and ordinary care on the part of the engineer in charge, this was a difficulty to be overcome.

He was glad the Author of the Paper laid stress on simplicity

TABLE 2.

—	Number of Hours of Steaming.	Number of Revolutions.	Boiler-pressure.	Vacuum in Condenser.	Lbs. per HP. per Hour.	Indicated HP.
			lbs.	Inches.		
A	49	111·219	17·165	26·28	2·6	43·0
B	48	105·8	16·862	25·97	4·26	38·05
B	48	106·116	17·04	26·22	4·05	39·98
A	48	107·21	16·77	26·92	3·02	40·136
	Coal consumed 31 per cent. in favour of A.					
A	51	115·038	16·03	26·77	2·75	39·0
A	48	108·24	15·82	26·6	3·35	40·22
B	52·30	115·167	17·25	26·03	4·25	40·39
B	48	107·65	17·21	26·32	4·635	39·04
	Coal consumed 31·35 per cent. in favour of A.					

and accessibility of parts; for the tendency amongst shipowners had of late been for multiplying details and adding complication of parts. Many such appliances which might be serviceable on land or in smooth waters, were quite out of place when a ship was tossing about over Atlantic waves. The Author said that the owner of steamships preferred safety to science; but he expected the science he spoke of must be a misnomer. The Author also enlarged on the advantages of a long stroke and great velocity of piston travel; but, although inclined to agree with him generally, he did not when he characterised the short-stroke cylinders as "wasteful abortions;" he was induced to think he had some very inferior machine in view; for it so happened that the most economical engine he knew of had a short stroke of about $\frac{1}{3}$ of the diameter. The stroke of piston was 33 inches, the diameter of the large cylinder 100 inches. The speed of the piston was 530 feet per minute. The vessel which had these engines was her Majesty's ship "Briton," where the consumption was under 2 lbs. per indicated HP. This vessel was tried in 1870, and, he believed, at the time these engines were taken in hand there was no instance of an engine with a piston of 100 inches diameter making 96 revolutions per minute. He had often heard it said that the compound engine had the disadvantage of not being able to work with much variation in the speed or power of the engine. He had, therefore,

selected certain examples to show that the compound engine could work with a large variation of power. Table 3 showed three

TABLE 3.—INDICATED HP. at THREE VARIOUS SPEEDS.

Taken from cards of H.M.S. "Boadicea's" engines, 1876.

—	Number of Revolutions.	Steam in Boiler Room.	Steam in Engine Room.	Mean Vacuum in Condenser.	HP. of High-pressure Cylinder.	HP. of Low-pressure Cylinder.	Initial Pressure from Atmospheric Line HP. Cylinder.	Total HP.
1	10·5	..	..	27½	33·02	39·43	5·75 below	72·45
2	37·0	..	36	27	702·70	442·60	29·50above	1145·3
3	75·3	70	64	25½	2446·00	2194·00	66·00 „	5640·8

INDICATED HP. at THREE VARIOUS SPEEDS.

Taken from cards of H.M.S. "Bacchante's" engines, 1877.

1	30	..	40	28·0	360·0	254·4	8·3above	614·4
2	55	68	65	28·3	1838·0	1563·4	60·9 „	3401·4
3	73·36	70	65	26·7	2441·4	2990·9	61·8 „	5432·3

trials of the "Boadicea," with powers varying from 72 to 5,640 horses, or the greatest was $\frac{1}{78}$ of the least. The revolutions varying from $10\frac{1}{2}$ to $75\frac{1}{3}$ per minute. That of the "Bacchante" showed a variation of from 614 to 5,432 horses. The maximum power of each of these two engines was the largest, he believed, by nearly $\frac{1}{4}$ that had been obtained from any compound engine yet tried, acting on a single shaft and propeller, and was worthy of recording in the progress of steam navigation. Now, as to the future improvements, it seemed to him that, as the weight of the hull and machinery formed so important a consideration in a successful steamship, these permanent weights being as much as $\frac{1}{2}$ or $\frac{2}{3}$ the total weight of the ship, anything that could be done to diminish them, without making the vessel of a weaker construction, was most desirable. The better manufacture of steel, both in plates and bars, either by the Bessemer or Siemens process, offered opportunities for diminishing these weights by about $\frac{1}{4}$ or $\frac{1}{5}$. The only difficulty was how to preserve the surface of the steel; for he thought it was the experience of most engineers that steel did waste away much more rapidly than iron, especially in sea-water and a hot climate; good paint required renewing; and Portland cement, although a most effectual preservative, added to the weight. He

might mention the case of some iron and steel small vessels, which were sent to the eastern seas, where the steel hulls only lasted from three to four years, whereas the thin iron hulls lasted from twelve to fifteen years. The Admiralty Boiler Committee, he believed, had been making a variety of experiments on steel and iron, and he believed he was right in saying that a six months' trial showed that the average of the steel plates wasted away five times as fast as the ordinary iron, under certain circumstances; but whether similar circumstances existed with regard to the action of sea-water on the hull of a ship he was not prepared to say. As regarded the weight of the engines, the Whitworth metal came in well for making the shafts and other parts hollow, and consequently lighter. The "Bacchante" screw shafting had been so made; the outside diameter being the same as the "Boadicea's," but the metal was only 3 inches thick. As regarded the future economy of fuel, he was inclined to think that a good deal had yet to be done without increasing the boiler pressure by having the best machinery and workmanship, and by having the most efficient engineers, and paying them well, in order to make it worth while for careful and good mechanics to remain on board and look after the machinery.

Mr. F. J. Rowan, through the Secretary, directed attention to some facts connected with the historical part of the subject dealt with in the Paper, which had not been noticed by the Author. They were an important feature in the history of the development of steam shipping, because, as Mr. Samuda had remarked, every bold stride from the beaten track deserved to be noticed, if not for its own value as regarded results achieved directly by it, at least for its effects in inspiring others with courage to advance. They had also an undoubted importance in view of that progress which was desired for the future by all who were interested in steam shipping or marine engineering, because they offered a practical demonstration that a large measure of that advancement had already been attained in numerous instances. In 1859, Mr. James Robert Napier, of Glasgow, communicated to one of the Glasgow newspapers some results, observed by him, of the working of the steamship "Thetis," then running regularly as a trading vessel between Glasgow and Liverpool. This vessel was built by the Messrs. Scott, of Greenock, the engines and boilers having been designed by his father, the late Mr. J. M. Rowan, and his partner, Mr. T. R. Horton. Her dimensions were about 190 feet length, 26½ feet breadth, and 15 feet depth. She was fitted with compound engines of about 240 indicated HP., with a surface condenser and

boilers for steam of 115 lbs. per square inch. The late Professor Rankine had reported that, on a trial carried out under his professional supervision, she had developed a mean of 226 HP. upon a consumption of 1·018 lb. of coal per HP. per hour, the coal having evaporated 11 times its weight of water, the boiler having had 9 square feet of heating surface per lb. of coal consumed per hour, and the theoretical evaporative power of the coal having been about 15½. Mr. Napier's letter, a copy of which followed, was valuable as being the record of the maintenance of similar good results in the face of all the practical difficulties of regular trading; and a consideration of the date at which this system of high-pressure steam with compound engines and surface condensers was practically demonstrated, justified a remark of his that his father and those associated with him not only anticipated Messrs. Randolph, Elder and Co., but actually did that which they either did not attempt or failed to do.

LETTER TO THE EDITOR OF THE "NORTH BRITISH DAILY MAIL."—THE EFFECTS OF RECENT IMPROVEMENTS IN STEAM NAVIGATION.

SIR,—To get regular, rapid, and cheap communication by sea with all parts of the world is a problem which has been but partially solved; and though engineers have for a long time been trying, it is but recently that the heavy cost involved in the fuel has been so greatly reduced as in most cases to render Government assistance unnecessary. Every decrease of fuel has increased the traffic, extended the limits of the voyage, and equalised its time. The screw propeller was for most voyages found to require considerably less fuel than the sidewheels, and a rapid increase of steam-propelled vessels followed its introduction. The longest voyages were tried with these vessels; but the fuel required for steaming the whole distance was so great, and so little space left for profitable freight, that this mode of performing it with existing vessels, except with Government assistance, was soon abandoned for that partial use of steam which has rendered the voyages of such vessels as the "Great Britain" and "Royal Charter" so successful. One vessel, however, is now being constructed of a size so great, that fuel for a voyage equal to the globe's circumference, to be performed at the rate of about 400 miles per day, can be put on board in Britain, and withal leave a large space for profitable freight. Mr. Scott Russell, the builder of this big ship, lately told the members of the British Association that it was the *smallest* vessel which could perform the voyage in the time, without coaling by the way, and which would have space sufficient for freight to make the undertaking profitable to its proprietors. Mr. Russell was probably right in what he stated at the time, but not now. The theory of the steam engine established by Watt has been laid aside, and one of heat engines, in general more in accordance with facts, is being gradually adopted. This theory has shown the direction in which a saving is to be found. The steam of ordinary engines has been heated, and a saving of from 15 to 30 per cent. of fuel obtained. New engines have been made, hotter steam used, and upwards of 70 per cent. of fuel has been saved. The most remarkable case of economy, from the use of hotter steam, with which I am acquainted, is that of the screw steamer "Thetis,"

reported by Dr. Rankine to have consumed 1 lb. of fuel for the horse power indicated. This vessel has been trading for months between Glasgow and Liverpool, and astonishing all with the small quantity of fuel required. I took a voyage lately to see if the results were maintained; and although I was unable to get a card from the engine to show its power, I got some results which may be trusted. The vessel is, I believe, 190 feet long, 26½ feet broad, and 15 feet deep; has a propeller 12 feet diameter and 23 feet pitch, and was loaded with about 300 tons weight of cargo to a draft of 11½ feet of water aft and 10 feet forward. The mean velocity during the voyage of 190 geographical miles was 8·78 miles per hour, with a head wind during more than two-thirds of it. The mean pressure on the boiler during the voyage was 82·60 lbs. above the atmosphere. The mean revolutions of the propeller shaft were 45⅛ per minute, and the fuel consumed during the voyage was at the rate of 3·45 cwts. per hour. This, I think, is from one-half to one-third of the fuel used by steam vessels in general; and as there was nothing in the appearance of the machinery to indicate a greater deterioration or falling off of efficiency, than in any machinery of the ordinary construction, I have no reason to suppose that it will not last as long as ordinary engines; and one reason for thinking it will last, and be efficient considerably longer, is the boiler being supplied with fresh instead of salt water. I believe that the saving is so great that the money received for the extra freight, and the fuel saved, will in many, if not in all cases, be more than twice the Government subsidy; so that if subsidised companies are profitable, a non-subsidised company, having machinery as economical as Mr. Rowan has introduced on board the "Thetis," will certainly be much more profitable.

JAS. R. NAPIER.

From that year until about 1862, eleven or twelve sets of similar machinery were fitted in steamers, principally by Messrs. the Greenock Foundry Company, and by Messrs. R. Stephenson and Company, of Newcastle-on-Tyne. In these the same elements in general were employed, but the steam pressure was increased to 120 lbs. per square inch. Alterations and modifications were introduced, in some cases with good and in others with bad effect; but the history of this advance in marine engineering differed in nothing from that of the combination of failures and successes which experience showed was inseparable from every such invention. A sufficient number of examples, however, endured years of work, and remained to prove the substantial correctness of the system; and within the last four years further examples working steam of 150 lbs. pressure, on a regular consumption at sea of 1½ lb. of coal per indicated HP. per hour, had been added. The Author had asserted that the consumption of the best specimens of compound engines with the ordinary boilers varied from 2 lbs. to 2½ lbs. of fuel per indicated HP. per hour, and that the greatest degree of economy he hoped for during the next twenty-five years was a reduction of 20 per cent. upon that amount. He ventured to say that there was no need to wait twenty-five years to see that hope fulfilled; for a consumption of 1¾ lb. to 2 lbs. had actually been

maintained in the past, and one of 1 lb. to 1½ lb. had already been demonstrated to be possible and practicable, by means of steam of 150 to 200 lbs. pressure efficiently generated and used.

The questions of boiler design and working entered largely into the consideration of this matter; and believing that the only proper road to success in these lay in the strict observance of scientific principles of natural action—often contravened with bad results in actual engineering work—he regretted the Author's remark, which seemed to place "the safe and the scientific" in opposition as though they were incompatible. He was persuaded that it was not so, and that in the long run engineers would in this matter, as already in others, reach their desired end by an intelligent submission to truth.

Mr. P. SAMSON remarked, through the Secretary, that the Author's charges against the Board of Trade were of so general a character that it was impossible to discuss them fully without opening up the whole question of Government interference with merchant shipping. An Act of Parliament had been in existence since 1854, which imposed on the Board of Trade the duty of carrying its provisions into effect by a staff of competent surveyors. By the provisions of the Act a shipowner was not allowed to embark passengers in a steam vessel unless she had been surveyed by, and declared fit for the service intended, by one of the surveyors appointed by the Board of Trade. There was also a clause in the same Act which provided for inquiries to be held by magistrates, assisted by assessors, in the event of serious accidents to hull or machinery. When a steam vessel had been surveyed under the Act, the surveyor, when satisfied that she was fit for the service intended, made a written declaration to that effect and handed it to the owner. The owner, in turn, forwarded it to the Board of Trade, who issued the statutory certificate. As the law stood at present, the surveyor must satisfy himself that the hull, machinery, and equipments were sufficient for the service intended, or leave himself open, in the event of an accident, to censure, or even to be tried for manslaughter where loss of life had taken place, if it were proved that he did not use due care or vigilance in surveying the vessel previous to granting his declaration. When once the declaration was granted it was the practice of these Courts to regard the shipowner as morally, if not legally, free from blame, even if the boilers should burst or the ship founder on her next voyage; and he thought no legal tribunal could, with justice, convict the shipowner for sending his vessel to sea if he held the declaration of a Government official that the ship was fit for the

service intended, unless it could be proved that the surveyor was intentionally deceived, and the owner knew of the defective condition of the vessel. The duties of the surveyor were therefore of a most onerous and responsible character, and his position, placed between the shipowners and the public, was of the most delicate kind. On the one hand, the shipowner, in his anxiety to make his vessel profitable, urged the surveyor to complete the survey in the shortest possible time; on the other hand, the public punished the surveyor if he granted his declaration without being fully satisfied with the safety of the ship. There were two ways of satisfying the surveyor: firstly, by personal inspection and calculation made by himself; and secondly, by personal inspection, coupled with calculation made with standard rules by some person in whom he had confidence. Both methods involved a large amount of tedious calculation, and were the first system attempted, at each survey the detention of the vessel while the calculations were being made would become a serious matter for the shipowner, and the present staff of surveyors would, at least, have to be trebled. The first system should be only resorted to when vessels were surveyed for the first time, and the second system at subsequent surveys. To carry out this system the surveyors must not only be satisfied with the honesty and ability of their brother surveyors, but they must be acquainted with, and satisfied that the rules adopted by each other were reliable and based on sound principles.

The accepted rules for regulating the scantling of the hulls of iron vessels were considered by most surveyors as sufficiently reliable, and these rules were generally used by them in the execution of their duty, and if added to the Book of Instructions would not make any material alteration in the present practice of the surveyors. Had the rules for boiler construction been in an equally satisfactory condition a few years ago, there would have been no necessity for the Board of Trade to issue the rules complained of by the Author, and a great amount of expense, thought, and labour would thereby have been saved to the officers who advised the Board on these matters. At the time these rules were published the steam pressure was rapidly increasing, and the workshop appliances were inadequate for manipulating the thick plates required for the shells of cylindrical boilers. It was also generally believed at that time by manufacturing engineers, that if a joint were double riveted its strength would be equal to 70 per cent. of the solid plate. These circumstances combined caused many double-riveted joints to be so malformed that the least section of plate or rivet was, to his own knowledge, in some cases reduced to

42 per cent. of the solid plate. Again, many engineers asserted that the plates they supplied had a tensile strength of 23 tons per square inch. These beliefs and statements were doubted by the Board of Trade, and it was resolved to make a few experiments to obtain information. The preliminary experiments conclusively proved that the strength of a double-riveted joint was not equal to 70 per cent. of the solid plate unless the quality of the iron was high, and the percentage of metal left between the rivet-holes was equal to 70 per cent. of the solid plate; and, further, that the rivet section must be equal to the net plate section if the plate was of medium quality. These experiments also showed that instead of boiler plates having a tensile strength of 23 tons per square inch, from 20 to 21 tons was nearer their value. The effects of punching different qualities of iron were also ascertained, and the injury found to be, in some cases, far in excess of what had been anticipated. These experiments had been followed by a most exhaustive series on riveted joints, the results of which corroborated the preliminary tests. The tests on joints would have been incomplete in themselves without experiments on actual boilers, as many engineers believe that crossing the joints of a cylindrical shell would add considerably to the strength of the longitudinal seams. This opinion appeared to have been shared to some extent by Sir William Fairbairn, as would be seen on referring to his most valuable work entitled "Useful Information for Engineers." The issuing of the Board of Trade rules had the effect of causing many engineers to investigate the subject of riveted seams, and two of the most influential manufacturing firms in the North, with a praiseworthy desire to gain experimental knowledge, burst two cylindrical marine boilers and a cylindrical superheater by hydraulic pressure to ascertain their strength. These experiments fully confirmed the rules in the Book of Instructions, which had been formed on the strength of riveted joints only, and corroborated in a remarkable degree the opinions held by Mr. Traill for many years previous to the Instructions being issued. A few years ago the Author appeared to hold very strong views on the subject of the strength of cylindrical shells of boilers, and went so far as to write a Paper on the subject. He asserted in the Paper and to the Board of Trade that the way to calculate the strength of the cylindrical shell of a boiler having the joints shifted, as in brickwork, was to draw a line from one end of the boiler to the other, through the joints and solid plate, and take the mean section of the plate in that line as the strength of the joint. Mr. Traill had asserted that by calculating the strength of the shell

of a boiler by that method the results are from 50 to 85 per cent. per cwt. from the truth. It was worthy of remark that in each of the three experiments the plates of the outer shells were fractured through the rivet-holes of the longitudinal seams, thereby clearly proving that the cylindrical shells of modern marine boilers were the weakest portion. By calling the strength of the joints 70 per cent. of the solid plate, and taking the ascertained tensile strength of the material, the results were also very wide of the mark, as would be seen from the following figures:— Calculated bursting pressure of No. 1 boiler, about 348 lbs.; actual bursting pressure, 230 lbs. Calculated bursting pressure for No. 2 boiler, 284 lbs.; actual bursting pressure, 195 lbs. Calculated bursting pressure by Board of Trade rules for No. 1 and No. 2 boilers, 229·3 lbs. and 194·7 lbs. respectively, or less than 1 lb. from the actual bursting pressure in each case. These figures were sufficiently convincing to his mind that the Board of Trade did good service to all persons interested in the "progress of merchant shipping" by providing a rule for boiler shells which had no equal for accuracy. Sir William Fairbairn's rule for cylindrical furnaces was quite as unsatisfactory as the rules for cylindrical shells. The defects in Fairbairn's formula for flues were detected by the Board of Trade officers from a careful study of the results of the experiments recorded in the work called "Useful Information for Engineers," and the modified rule in the Book of Instructions was the result of that investigation. Within the last month two full-sized cylindrical furnaces had been made and tested to destruction by hydraulic pressure, to ascertain their strength to resist a crushing force. These experiments showed that the Board of Trade rule had a factor of safety of 6·2 in one case, and 5·5 in the other, and that the collapsing pressure by Fairbairn's rule, viz., $\frac{806 \cdot 300 \times T^2}{L \times D}$ = collapsing pressure, was in one case 68 per cent., and in the other 88 per cent. above the actual collapsing pressure, and if the formula $\frac{806 \cdot 300 \times T^{2 \cdot 19}}{L \times D}$ = collapsing pressure were used, the errors would be 47 per cent. and 56 per cent. respectively. The rule for flat plates supported by bolt stays was the result of combining the practice of the best makers throughout the country with the results obtained from testing experimental boxes stayed as in boiler-work. Previous to the date of these experiments, stays were in very many cases pitched by rule of thumb, and the plate between screwed stays without nuts was allowed as great a pressure as when the stays

were fitted with nuts, and the strength of the plate was supposed to vary as the square of its thickness. From these and subsequent experiments, made in one of Her Majesty's Dockyards, it was known that the usual thickness of plate supported by stays fitted with nuts was from 30 to 50 per cent. stronger than when the stay-ends were screwed and merely riveted over; and further, that the strength of the plate did not vary as the square of the thickness, as previously supposed. The calculated bursting pressure by the Board of Trade rule for the box tested in the Dockyard was only about 1 per cent. greater than the actual pressure, and the calculated bursting pressure for two other boxes tested a short time ago was not more than 3 per cent. from the actual bursting pressure. As the thickness of the experimental plates ranged from $\frac{3}{16}$ inch to $\frac{1}{2}$ inch, and the pitch of the stays from 8 inches to 15 inches, he contended that the rule gave results quite near enough for all practical purposes. The rule $\frac{C \times T^2}{P^2}$ = working pressure previously adopted by many engineers was to be found in standard books. If this rule were tested by the results of the experiment to which he had referred, it appeared somewhat absurd, for when the plates were of unequal thickness, and the pitch of the stays alike, the error was more than 20 per cent., and when the plates were of equal thickness and the pitch unequal, the error was no less than 35 per cent. The rules for safety-valve area in the Book of Instructions were not quite so satisfactory as he could wish, but it must be remembered that a committee of the Institution of Engineers and Shipbuilders of Scotland investigated this subject and published a most able report, in which they endeavoured to show that the area of safety valve required by the Board of Trade was too small for certain pressures, and on the other hand many engineers, chief of whom was the Author, had been writing pamphlets and endeavouring to prove that the same safety-valve area was excessively large. Under these circumstances the Board of Trade might be excused for adhering to the old practice, until engineers either agreed among themselves, or left the Board's officers to do what was best for all persons interested. From his own investigation of this important subject, he had no hesitation in stating that had the Author's advice been taken in the matter of safety-valve area and boiler construction, the lives of many men would have been placed in imminent danger. With regard to the remaining rules in the Instructions, he would merely state that they would bear as close investigation as the others, and give results equally satisfactory.

The Author contended that the regulations were not approved by well-informed engineers, and that this was proved by the dissatisfaction and irritation they had produced, and the remonstrances made by important associations. He did not think the Board of Trade would for a moment dispute the fact that some engineers had been displeased with the rules in the Instructions, but those engineers had been a small minority. Of this there was sufficient proof in the contents of a large number of letters received from manufacturing engineers, and others equally interested, who highly approved of the rules. The only remonstrance raised against the Instructions emanated from the manufacturing engineers of the Clyde district, but it was exceedingly laboured, and altogether unworthy of so talented a body. Besides, the reply they received to their objections appeared to have carried conviction, for they had been since that time silent.

The Author had drawn a comparison between the locomotive boiler and the marine boiler, which he considered altogether unfair, for the following reasons: locomotive boilers were, he believed, usually designed and made by locomotive superintendents, whose professional qualifications were generally of the highest order, and first cost was of little moment to a large company so long as a good boiler was secured. The designer had, besides, the purchasing of the plates and other material, and the workmen were under his control; and further, he had command of the purse and workshops of a powerful company. As workmen in railway locomotive works were not discharged to-day and taken back to-morrow, as was the case in many marine engineering works, they acquired a better knowledge of the ideas and wishes of the designer, and, on the whole, took a much greater interest in their duty. The boilers made by each railway company were of almost uniform type and dimensions, and the pressure carried was practically a constant. This circumstance rendered a mistake almost impossible, and the eye alone became so accustomed to the stereotyped form and dimensions, that it at once detected any departure from the usual practice. The designer of the boiler, having the control of its work, inspection, and repairs, could regulate its duty to suit the circumstances, and take it into the workshop for repairs as the nature of the defects might require; and further, the periodical inspections might be made as minute and searching as designer or circumstances demanded. The load on the safety valves of a locomotive boiler might be taken as the maximum pressure to which it was subjected, for as soon as the engine stopped, the generating power of the boiler was checked, and in a few minutes afterwards

it was practically nil. The cylindrical portion of a locomotive boiler, like the shell of the modern marine boiler, was, under ordinary circumstances, undoubtedly the weakest portion of the structure, but it was not subjected to the excessive racking forces from unequal expansion, and consequent leakage and corrosion like the latter, and explosions of locomotive boilers had not been attended with so great a loss of life as explosions of marine boilers in passenger vessels and in men-of-war with crowded stoke-holes; and he certainly thought that railway travellers sitting in a train behind a locomotive were less liable to injury from the explosion of the boiler, than the passengers of a river steamer crowded on the deck immediately over the boilers. The difficulties presented to the marine engineer were greater by far than were ever met by locomotive superintendents, for the steam pressure and form of boiler were ever varying to suit the requirements of the ship or engine. The result of this condition of things was that the eye never became so accustomed to the dimensions and distribution of the stays, plating, &c., as to enable even an experienced engineer to tell at once the strength of a boiler, without first making minute calculations; and further, the marine boiler was usually made by contract, which meant, in many cases, either low-class material or workmanship of an indifferent kind, and occasionally even both. The tools and other appliances in the works of some marine boiler makers were quite unsuitable for the purpose of turning out first-class boilers; and it was often the case that surveyors were unable to ascertain even the name of the maker of the boiler they were called upon to survey. The rivet-holes of marine boilers were, in a large number of cases, punched, and the rivet-holes drifted to make them fair, the effect of which was to damage the plates to an alarming extent, especially when the plates were thick and of poor quality. Again, some marine boilers were under steam for long periods, to meet the exigencies of the trade in which the vessel was placed, which prevented inspection or even necessary repairs being executed, until what at first might be a slight leak became a serious defect. Some marine boilers, too, had been found to suffer from excessive oxidation, and others from a deposit of lime on the parts exposed to the fire or hot gases. The natural draught of the marine boiler being independent of the exhaust of the engine, the steam was generated at the same rate with the engines at rest as when they were at work; hence in practice, when the engines were suddenly stopped the steam rose in the boiler about 10 per cent. above the loaded pressure. The straining force in boilers loaded to 100 lbs. was therefore 110 lbs.;

and further, it was seldom that every part of a boiler was sufficiently strong by the rules for the pressure required, and in such cases a range of 5 per cent. was usually allowed. The maximum straining force in many boilers passed by the Board of Trade was, therefore, 15 per cent. above the calculated load. As surveyors granted their declaration for periods of twelve months, they had to be guided, when fixing the working pressure of a boiler, not only by its condition at the time of inspection, but chiefly by its probable condition when the certificate expired; and it should be borne in mind that a passenger vessel, by the Act of Parliament, must be in a condition to make her last voyage with as much safety as the first; and that the surveyor who granted the declaration, unlike the locomotive superintendent, had practically no control whatever over the working, inspection, or repairs of the boiler. All those who had examined locomotive boilers laid aside as unfit for further use, and worn-out marine boilers as they were removed from ships, must have been impressed with the greater margin of safety still left in the former compared with the latter.

In reference to the factor of safety of modern marine boilers as made by recognised first-class makers, the experiments to which he had already referred furnished the means of ascertaining the actual factor of safety with some degree of accuracy, and he would here draw special attention to the important difference between a nominal and an actual factor. As the latest experiments showed that the cylindrical shell was the weakest part of a modern marine boiler, he would deal with that part only. The nominal factor of safety in the rules of the Board of Trade for the boilers and superheater experimented upon was 7; and if the plates had the tensile strength allowed in the formula, the actual factor of safety would also have been 7, but the plates became fractured between the rivet-holes with a mean stress of only 15·5 tons per square inch. To ascertain the actual factor of safety, it was merely necessary to reduce the nominal factor 7; as 15·5 tons were to the tensile strength allowed in the rule, which was 23 tons. In this way it was found that the factor was 4·7, assuming the greatest pressure in the boiler to be the load on the safety valves; but as the steam pressure rose, on an average, 10 per cent. above the loaded pressure, 10 per cent. had to be deducted to obtain the actual factor of safety, 4·3.

Sir William Fairbairn, in "Useful Information for Engineers," recommended in some parts a factor of 8, and in others a factor of 6; and Professor Rankine stated in his writings that boilers should be made to withstand a pressure six times greater than the

working pressure; while Dr. Anderson, in his work on the strength of material, stated that 7½ was not by any means too much for a new boiler, because corrosion and other causes soon reduced the original strength. Comparing the factors of safety recommended by those high authorities with the actual factor of safety possessed by high-class marine boilers passed by the Board of Trade, he thought that body could not with justice be charged with being wedded either to the opinions of others, or with demanding too much security for the travelling public.

The Author held that resistance to novelties might be expected and preference given to stereotyped form, but before accepting this as an axiom he would direct attention to the results of the past. During the time embraced by the Paper the Board of Trade had been intimately associated with merchant shipping, and looking to its past and present proportions, he thought all would admit that if the Board of Trade had not contributed to its "rise and progress" they had, at least, not put such obstacles in the way as would impede its growth. The past proved that the Board of Trade was not wedded to stereotype forms, for within the last twenty or thirty years the wooden passenger steamer had given place to the short iron steamer, the short iron steamer to iron vessels of excessive length to breadth; and at the present day vessels of steel were likely to supplant those made of iron. The improvements of the engines in the period stated had been quite as marked as those of the hull, for paddle engines had been superseded for ocean purposes by common screw engines of innumerable types; and again, common screw engines by the various forms of the compound screw and paddle engines. The surface condenser, centrifugal pumps, steam stearing gear, and numerous minor improvements had also been introduced. He would even say that there was not a single improvement of any importance which was not to be found in the passenger vessels surveyed by the officers of the Board of Trade. To assert that an undue resistance would be opposed to novelties was as unjust to the Board of Trade as it was uncharitable to the officers intrusted to carry out the wishes of the nation in reference to merchant shipping. It had been suggested that manufacturing engineers should have a voice in framing the rules on which the surveyors acted, but he feared few successful manufacturers would take the trouble or accept such a responsibility; and if successful manufacturing engineers were not to be obtained, he did not think it would be prudent, or for the benefit of those interested in merchant shipping, to employ engineers who had been unsuccessful in their profession. By the present arrange-

ment of the Board's advisers manufacturing engineers and shipbuilders of this country communicated information freely to the Board of Trade when requested, and the staff of surveyors, meeting as they did manufacturers of all grades and opinions in their district, were well able to supply useful information. Were only a few of the manufacturing engineers to be intrusted with the framing of rules for the department much jealousy would probably soon arise amongst them, for they, as a body, were very self-opinionated, and each considered his ideas superior to all others; and he thought it highly probable that the mutual good feeling now existing between the Board of Trade and the manufacturing engineers would suffer, if not be entirely destroyed.

Mr. RICHARD SENNETT stated, through the Secretary, that his views agreed generally with those so ably enunciated by the Author. The principal point on which he would submit a few remarks was, the third great change in construction, which the Author justly asserted had rendered possible the great extension of steam navigation during the last twenty-five years, viz., the compound engine; and he thought most steam-users would agree with Mr. Holt that the introduction, or more properly, the adaptation, of the compound engine for marine purposes had the chief share in bringing about the great increase of steam navigation during the past quarter of a century. There could be no doubt that, *cæteris paribus*, the higher the initial pressure of steam used, the greater would be the duty performed by a given expenditure of heat. For example, the quantity of heat required to generate 1 lb. of steam at a pressure of 14 atmospheres was only 1·04 times that necessary to generate it at a pressure of 1 atmosphere, the temperature of the feed-water in each case being 100° Fahrenheit. The work possible to be done by 1 lb. of steam at the higher pressure was, however, more than four times as great as that possible to be done by the steam at the lower pressure, the final pressure in each case being 1 atmosphere. The economy of high pressures being admitted, the problem was reduced to finding the engine most suitable for the use of high pressures. Theory and practice both tended to show that high pressures could only be safely and economically used in the compound engine.

The advantages of the compound marine engine might be thus summarised:—

1. Reduction of the maximum strains on the framing, shafting, and bearings, and consequent reduction of weight and cost.

2. Increased regularity of turning moment, and consequent increased efficiency of the propeller in the water.

3. More economical use of the steam in the cylinders, and consequent increase of power from a given expenditure of heat.

The first two points were almost self-evident, but on the third there appeared to be some difference of opinion, and it had been stated that the gain in economy of steam by the use of the compound engine, if any, was so slight that it was more than counterbalanced by the increased complexity and cost of repair. It was to this point principally that he wished to refer. First, as to the economy of steam; the compound engine was only the logical extension of James Watt's principle of keeping the steam cylinder and the condenser separate. The idea was evidently to keep the vessels in which the steam was used at as nearly a constant temperature as possible. In a single expansion cylinder the temperature during each stroke varied from the initial temperature of the steam to the temperature of the condenser, whilst in the compound engine this difference was divided into two or more stages, which much reduced the loss by liquefaction. This loss by liquefaction was an indirect loss, and acted by the reduction of the initial and increase of the final temperatures and pressures, by which the efficiency of the steam was reduced; and at each stroke a quantity of heat was expended in simply raising the temperature of the surface of the cylinder, the heat passing away to the condenser without performing any useful work. On account of liquefaction it was impossible to carry out a high effective rate of expansion in a single cylinder made of conducting materials such as were necessarily used at present. He need not enter into details to prove this, as these points were generally admitted. But some opponents of the compound system averred that this gain in economy was more than counterbalanced by the increased complexity and cost of repair. This, however, was not necessarily the case. In the first place, there need be no greater complexity in the compound engine; but, on the contrary, with the same pressures of steam and rates of expansion as in a single expansion engine, the simplicity of construction should be on the side of the compound engine, if properly designed. Expansion valves might in many cases be dispensed with in compound engines, for, by proper setting of the slide valves, the ordinary ratio of cylinders used would give an expansion of from five to eight times at full power without any additional gear, and any increased expansion required for reduced powers could easily be obtained by use of the link. For a single expansion engine working at the same rates of expansion, separate expansion gear suited for early cut off would of neces-

sity have to be used, and this of itself would introduce increased complexity.

The Author had spoken of the complexity and weight of castings required for the two-cylinder compound engine. This, however, was not necessary. At first it was considered essential that these engines should be fitted with a large receiver between the high and low-pressure cylinders, and as this was generally cast around the high-pressure cylinder, it made a heavy and complex casting. This idea had now been abandoned, and some of the most successful two-cylinder compound engines had been made without any receiver, the exhaust pipe leading from the high to the low pressure cylinder, and the steam passages, &c., containing quite sufficient space for the steam before entering the low-pressure cylinder; and this system had rendered the castings quite as simple and light as for single expansion engines. The difficulty of starting that had sometimes been experienced with these engines was not inherent to the system, but was more a matter of detail than of principle, and, as the Author mentioned, had never amounted to a serious objection in practice. He was of opinion that the two-cylinder compound engine, or in case of large powers, in which a single low-pressure cylinder would be unwieldy, its counterpart the three-cylinder compound engine with one high and two low-pressure cylinders, was much more likely to come into general use than the four-cylinder engine with two high and two low-pressure cylinders, as it was, on the whole, more convenient and durable, occupied less space and weight, and was less liable to derangement. The superiority of compound engines over simple engines would be more demonstrated as the engines became worn. When the slides and pistons began to leak the loss would be much greater in the simple than in the compound engine, in consequence of the greater ranges of pressure in the simple engine. The steam that leaked past the piston in a simple engine would go direct to the condenser without doing any useful work, whilst in the compound engine the steam leaking past the high-pressure piston would have a chance of doing work in the low-pressure cylinder before getting to the condenser. The almost universal adoption of compound engines by steam-ship owners must prove that the economy and efficiency resulting therefrom were a reality, and that the course taken had not been from caprice or fashion, as had sometimes been suggested. The results of the few instances in which simple engines with high pressures of steam and high rates of expansion had been tried, both in the royal and mercantile navies, had generally been unsatisfactory, and were not such as to

justify any extension of that system. If high pressures were to be used—and there was little doubt that the tendency was to increase rather than decrease the pressures employed—the compound engine was a necessity; and if properly designed, it should be simpler, lighter, cheaper, more efficient, and more durable than its single expansion rival.

He was sorry to find that the Author felt compelled to speak somewhat in condemnation of the steam jacket. Properly designed and used, it should tend to produce considerable economy, especially with high rates of expansion. It was not so essential with compound as with simple high expansion engines, but he believed it would be beneficial to either. It had been shown by many experiments that the saving from the use of the steam jacket varied from 10 to 20 per cent., according to the rate of expansion used. This would, however, depend to a great extent on the method in which the jacketing was carried out. Mr. Holt appeared to refer to the system in which the jacket and cylinder were cast in one, which would necessarily introduce complexity of casting, and generally a large portion of the cylinder would be unjacketed and exposed to the action of the exhaust steam. With the system now frequently adopted, of casting the working barrel of the cylinder as a separate liner, and bolting to the main casting, leaving a steam space all around it, there was no complexity, the cylinder was efficiently jacketed, and there was no doubt that much economy resulted from its use.

He must, in conclusion, take exception to the Author's distinction between the safe and the scientific. The truly scientific must be safe and must be simple. Where machinery was not safe and simple, it was certain that the so-called science had gone wrong. The principal aim of science should be to bring correct principles to bear on practical subjects, and as regarded marine engineering this should increase the simplicity, safety, and efficiency of the machinery used for propelling ships both of war and commerce.

Mr. W. SHUTE remarked, through the Secretary, that in his opinion the great importance of form in ships, with regard to their profitable employment, had been hardly sufficiently recognised, either by the Author of the Paper, or in the discussion; and that no allusion had been made to several other matters of importance connected with this subject. The total value of cargoes at any time at sea must now be hundreds of millions sterling; and the interest on this vast sum, amounting to tens of thousands of pounds per day, must be a loss to somebody, so long as the principal lay idle unnecessarily. Even though the merchant or shipper might

trade, or speculate, meanwhile with money borrowed on the security of these cargoes to arrive, nevertheless there must be certain saving, to the many parties interested, by bringing all cargoes to their market port as quickly as possible economically. With passenger traffic, speed was of yet greater and of increasing importance. If it proved possible to further shorten all voyages, economically, by even some small portion of their present duration, by improvements in the forms of vessels, as well as by improvements in their propelling machinery, it followed that more voyages could be made, and thus more profit earned in a given time; and also that fewer ships of a similar size would be needed for similar work than now. As already pointed out, there was a large fund ready, out of which to provide the necessary improvements for effecting these savings, and a sufficient promise of profit to induce attempts at driving improved cargo steamers in future at somewhat higher velocities than the 8 knots per hour, which now seemed the economical limit of speed for such vessels—for the quickest ships would naturally be preferred. Such increased speeds would probably be gained chiefly by improving the forms of ships, since improved shape meant decreased resistance of the water to the vessel, and a consequent saving of power and fuel, with increased space for profitable cargo; whereas increasing speed by increasing power usually meant more fuel consumed, and thus less space for cargo. And even where, owing to finer lines, space for cargo might be somewhat diminished, yet this would not necessarily cause loss of profit, as it would be fully compensated by the saving of power and fuel, and by the advantages which increased speed brought with it. With finer lined ships, coarser pitches of screws might be used; and though speed was always limited by increased resistance, yet a somewhat larger, if finer-lined ship, might be driven at the same speed as a smaller but worse formed ship, by an equal amount of power. Or if the displacement were the same in both types, then a higher speed might be attained by the better shaped ship, if it had equal power; or an equal speed attained by it with less power and fuel. The value of Mr. Scott Russell's wave lines seemed even now to be hardly enough appreciated and used in cargo steamers. By the use of steel it was now possible, in addition to using finer lines, to effect a further economy by the reduction in weight of hull, enabling an increased cargo to be carried safely. Also any future saving of power now lost from waste of fuel, or too low pressure of steam, or through the excessive friction of some parts and the arresting and reversing the momentum of other parts of the machinery, besides any saving of waste in the propeller, would

all tend, in well-shaped ships, to increased speed, at present impracticable or unremunerative in the existing types of vessels. Hardly any mention has been made of the many experiments tried in late years with varied types of ships; such as those of Mr. Winan's with cigar-shaped ships; nor of the experiments of Dr. Collis Browne with ship models having long submerged ends, similar to those used by Mr. Reed in the "Bessemer" Channel steamer originally, and also as rams in war-ships. Neither was much allusion made to Mr. Griffith's experiments with screw propellers working in tubes, open at their ends only, through or beneath a ship lengthways; nor to the water-jet system of propulsion—though all these would seem to deserve further trial and notice. The successful use of auxiliary power in connection with sail power in the Royal Navy had not been mentioned, nor the attempts a year or two since to utilise the rolling and pitching motions of sailing vessels as a source of power by compressing air, which was to be stored up for use in calms. The practicability of such economical expedients seemed worth discussing. Another matter not mentioned was the use of Mr. Penn's wood bearings for screw shafts, which, lubricated by water only, reduced the friction of those heavy and quick-moving parts of marine engines, which seemed almost unavoidable in full-powered steamers. Such an application of a current of water to keep down any frictional heating seemed specially suitable to the hollow steel shafts now coming into use, which could thus be cooled both from their insides and outsides. There would seem to be great difficulty as to what use to make in future of old-fashioned, though not worn-out steam ships and machinery, which had become both uneconomical to work, and difficult to dispose of. It often neither paid to alter them, nor to break them up as old metal, although this was usually their unsatisfactory ending. Some of these old ships, with machinery removed, might perhaps be used with advantage as floating barracks, or as sailors' homes and training-ships in sheltered ports or rivers.

Mr. W. H. WHITE, Assistant Constructor of the Navy, remarked, through the Secretary, that the Author had evidently approached the question more from the side of the marine engineer and shipowner than from that of the naval architect; and this fact affected both his observations on the past progress of steam shipping and its possible future. For example, in his remarks on the advantages of iron hulls, he said: "It has been possible to construct vessels of much greater displacement, in proportion to the power required for propelling them, than can be done in wood;" which was, to say the

least, an incomplete statement of the question. It was quite true that with iron hulls vessels had been built of greater speed, size, length, and proportion of length to breadth, than would have been possible with wooden ships; and it was an axiom in steamship construction that increase in size led to an economy of steam power, that economy being measured by the ratio of the expenditure of power to the commercially remunerative carrying power. Approximately, the conditions of practice for similar ships were that the expenditure of engine power varied about as the two-thirds power of the displacement, whereas the weight of hull and the carrying power varied nearly as the displacement: the speed in this comparison was supposed to be constant for all the similar ships compared. This rough statement would serve his present purpose, although it required several important corrections to make it conform accurately to the true general law of comparison. Take, for example, two cases from actual ships, one of 1,830 tons displacement, the other of 3,660 tons; each steaming nearly 13 knots: in the larger ship 2,400 HP. were required, in the smaller 1,600 HP. were expended. The larger ship had a cargo-carrying power of about 1,400 tons for a certain voyage, the smaller of about 600 tons for the same voyage. In other words, the increase in the size of the ship doubled the carrying power, but was accompanied by an addition of only 50 per cent. to the HP. Within certain limits, this economy of power was as realisable with wooden hulls as with iron; but the result depending on the difference between the two materials was that the process of enlargement could be safely carried farther with iron than with wood. With this enlargement, also, the iron ship could be made longer and finer than the wood, the resistance being diminished by the alteration of form, quite independently of absolute dimensions. Possibly this was the Author's meaning, but it was by no means clearly expressed.

Nor did he make any allusion to the fact that, in proportion to the displacement, the weight of hull was less in iron than in wooden ships, the carrying power being, of course, greater. Take two ships of equal size and identical form: give one a wooden hull and the other an iron hull, and the latter would be lighter than the other by about 10 per cent. of the entire displacement. In other words, as merchant ships were usually built, the iron-hulled ship would have a carrying power (excluding hull) of about 67 per cent. of the displacement, and the wooden ship of only about 57 per cent. For equal speeds, steaming capabilities, and coal endurance, equal weights of machinery and coals would have to be

taken in both cases; hence 10 per cent. of the displacement would be added to the remunerative cargo-carrying power by using iron, even in cases where the wooden hull might give sufficient strength. These facts were, he knew, well recognised by shipbuilders, but the Author confused them in a general statement, whereas it was necessary to distinguish between the effect of form, size, structural combinations, and the material of which the hull was built.

Had the Author named these separately, he could scarcely have failed to make reference to the probable effects upon steam navigation of the replacement of iron by steel hulls. This change was now very near, and it must largely influence the economical aspects of ocean steaming. For example, it was no exaggeration to suppose that a steel ship equal in strength to an iron ship could be built at least 20 or 25 per cent. lighter than the iron ship; that was to say, whereas in the iron ship about one-third of the total displacement would be required for hull, in the steel ship one-fourth would suffice, and the steel ship would gain upon the iron nearly as much as the latter would gain upon the wood. Hence there was every reason to hope that the Australian service and other long voyages would, by the use of steel hulls, be made commercially remunerative, even if there should be no further improvement in marine engines—which was a very improbable supposition. The iron ships at present running to Australia burned, say, about 1,600 to 2,000 tons of coal on the voyage out, in order to carry about 1,200 or 1,500 tons of dead-weight cargo; if steel hulls were used the dead-weight cargo might at once be enlarged by about 400 tons, without loss of speed or lengthening the time of passage. To effect a corresponding saving by means of economical consumption of fuel would need the average rate to be lowered from $2\frac{1}{4}$ lbs. per indicator HP. per hour to about $1\frac{3}{4}$ lb., or about 20 to 25 per cent. The Author despaired—perhaps unwisely—of doing more than reducing the rate of coal consumption 20 per cent. in the next twenty-five years; here he would find in the use of steel hulls an equivalent saving at once presented to him for the very longest voyages that had to be undertaken, where the economy of fuel was of the utmost importance. On shorter voyages the comparative gain by using steel hulls would be even more valuable. For example, a first class Atlantic steamer of 9,000 to 10,000 tons displacement would burn, say, 800 tons of coal with her present compound engines between New York and Queenstown. A saving of 20 per cent. on the rate of coal consumption would add 160 tons to the dead-weight carrying capacity; the use of a steel hull would add about 700 or 800 tons—five times as great as the former addition.

Lastly, he must draw attention to the fact that the Author took no account of possible savings in the weights of marine engines in proportion to their power. This was a serious omission; for there was every reason to expect that what had been done on a small scale by Mr. Thornycroft and others might be repeated on a larger scale. There surely could be no essential reason why, for engines up to say 400 HP., it was possible to get 1 HP. for about ½ cwt., whereas for ordinary engines the weight per HP. ranged from 3 to 4 cwt. Of course there were great difficulties in the way of passing from the torpedo launch type of engine, with its enormously rapid piston speed, to the engine suitable for driving the screw of a large ship; but he could see no reason why some progress, at least, could not be made in the direction of lightening marine engines without rendering them wanting in durability or efficiency. All that could be saved on engines, hull, or coal consumption, of course could be used up either in building smaller ships for a certain work, or in getting greater profits out of ships of a certain size and speed.

These criticisms on the Author's interesting Paper were not made in any unfriendly spirit, but simply to indicate points of omission, which when taken into consideration rendered it not unreasonable to anticipate continued progress in steam shipping.

Mr. Holt replied, through the Secretary, to the written observations made through the same medium, that several gentlemen founded exception to his statements as to the present consumption of fuel and his outlook for the future, on the fact that higher pressures of steam had already been used and were in practice, producing power for less coal than he had named. Notably, Mr. Perkins's interesting system had been referred to, and there were others also. But his intention had been to set forth, as far as he was able, the broad facts of the present position of steamers as presented to the eye of the non-scientific shipowner, or as accepted by the ordinary "laity." He was well aware that greater economies than those mentioned by him had been obtained, and he had been privy to some of the instances, and had, in fact, instances in his own vessels; but the class of machinery giving these results had not yet met with general acceptance, and might still not unjustly be described as in the experimental condition. In his statement of consumption of fuel, he invariably debited the engines with all the coals used in the ship, though aware that the galley and donkey boiler made away with some, and that coals taken abroad were generally of bad quality and deficient in weight. He felt that the best way to meet the statement, "that there was not even a speculative probability of the single cylinder ever forcing

aside the compound form," was to say that the combat between the two for superiority would probably, by the rough and ready shipowner, not be decided on the ground of coal consumption alone (though on that ground the experience of pumping engines was in favour of the single cylinder), but on the ground of lightness, durability, and simplicity, qualities which he thought would be considered almost as important as economy in the future, and were probably possessed in a superior degree by the single cylinder engine.

He regretted to have to recur to differences of opinion with the Board of Trade, but he could not leave unnoticed two points in Mr. Samson's statement of their case. One had reference to an effort made by him years ago to induce the Board to view the strength of the shell of a cylindrical boiler as a whole, attributing, when the joints were broken and the plates not too wide, a certain amount of support to the joint in one ring of a boiler to the fact of its lying in line with solid plates in the two adjacent rings. He thought it could hardly need proof that his contention contained a measure of truth; he would put a case on the old rule that "principles are best tested by their extremes." Suppose a boiler of, say $\frac{3}{4}$-inch plates, had one cylindrical ring 2 inches wide and no rivets in its joint, but lying between two ordinary rings, would that boiler possess no strength? According to the Board of Trade rules it would not, whereas, in reality, its strength would hardly be affected. He still held the opinion that, to view a cylindrical shell as a whole was the truest way of arriving at its strength, and that to judge of it merely by the strength of one joint was unfair. This was evidently not the case where the strength of a chain was that of its weakest link. The other point was where Mr. Samson said, "had Mr. Holt's advice been taken in the matter of safety-valve area and boiler construction the lives of many men would have been placed in imminent danger." With his advice on boiler construction he had already dealt. The only advice he could recollect having given on safety-valve area was when he suggested in 1871 the following rule: "To ascertain the square inches of safety-valve area. Multiply the grate-bar surface in square feet by a fraction, whose denominator is the proposed pressure in lbs. on the square inch, and whose numerator is always 18, but the area never to be required to exceed $\frac{1}{2}$ square inch to the foot of grate bar." If Mr. Samson doubted the sufficiency of that rule, he would be happy to make the experiment, bearing the cost if unsuccessful, if only the Board would adopt it if successful. His own opinion, much

strengthened since 1871, was that it erred on the side of giving unnecessary area. On the subject of safety valve areas he would try to draw a parallel with locomotive practice, because no one could doubt the efficiency and sufficiency of their valves. He had paid close attention to this somewhat difficult comparison, and he would give the results. A locomotive would, with about 17 square feet of grate bar, if kept at full stretch burn about 14 tons of coals in a day, and there was reason to believe evaporated about $\frac{1}{10}$ less water than an average marine boiler in proportion to the coal burnt. Therefore the quantity of steam produced by its boiler was about equal to that produced by a marine boiler having about 96 square feet of grate bar. The locomotive had about 14 square inches of safety valve, and the marine boiler would be required by the Board of Trade to have 48. It was argued, however, that the cessation of the steam blast diminished the production of steam and warranted small safety valves. But would this argument hold water? Was it not a constant occurrence that a locomotive urged to its utmost was nevertheless blowing off steam strongly, and in these circumstances liable to stoppage? If so, the entire yield of steam, at its utmost, must at once pass through the safety valves. Any way it would be highly imprudent to provide valves of less capacity. The steam-boat boiler, be it observed, being able to diminish its production as quickly and completely, if not as automatically, as the locomotive by opening doors and closing dampers. Besides, steamboats had easing gear which was never fitted to locomotives. His deduction from the whole matter was that locomotive practice warranted a large diminution of area from the Board's rule. He entirely denied that any recommendation of his involved risk to human life; all were well within the bounds set by the safest practice outside the Board of Trade, and he would be pleased to have more detailed argument on the subject than was possible in the proceedings of this Institution.

Mr. R. V. J. KNIGHT observed, through the Secretary, that various opinions had been advanced as to the amount of strength required to insure safety in marine boilers. Mr. Gray had spoken of factors 8 and 6, and referred to the opinions expressed by Sir William Fairbairn and Professor Rankine. Mr. Traill insisted on the retention of the factor 6, and quoted two examples as proofs of the accuracy of the Board of Trade rules for marine boilers. The Author and other gentlemen were in favour of a much lower factor, more nearly approaching to locomotive practice, but every one who had joined in the discussion appeared to have taken it for

granted that all boilers made in accordance with the Board of Trade rules have factors not less than 6, that was, that they would not burst with less than six times their working pressures. The rules to which he referred were published by Pewtress and Co., Great Queen Street, London, 1875. From the results obtained from the experiments he was about to record, it would appear that the factor of safety for large boilers, with double riveted lap joints made in accordance with these rules, did not exceed 4, if an allowance of 15 per cent. was made for crossing the joints, or a factor of $3\frac{1}{2}$ if no such allowance was made. The following experiments were made at his request in 1873, to ascertain the strength of some riveted joints; all the boiler-plates were of double best iron; all the holes were punched at 3 inches pitch, and all the rivets were closed by a hydraulic riveter, and the butt straps were double, each $\frac{5}{8}$-inch thick.

——	Lap A.		Lap B.		Butt C.	
Size of plates	Inches. 9 × 0·99	Inches. 9 × 0·99	Inches. 9 × 1	Inches. 9 × 1	Inches. 9 × 0·99	Inches. 9 × 0·94
Diameter of rivets. . .	Inch. 1·07	Inch. 1·07	Inch. 1·2	Inch. 1·2	Inch. 1·2	Inch. 1·2
Number of rivets . . .	6	6	6	6	12	12
Area of rivets	Sq. Inches. 5·39	Sq. Inches. 5·39	Sq. Ins. 6·78	Sq. Ins. 6·78	Sq. Inches. 6·78 × 2	Sq. Inches. 6·78 × 2
Area of remaining plate .	5·73	5·73	5·4	5·4	5·34	5·34
Broke through rivet-holes with	Tons. 62·5	Tons. 60·5	Tons. 69·1	Tons. 71·4	Tons. 93·6	Tons. 93·5
Broke through rivet-holes per square inch with .	10·73		13·01		17·5	
Ultimate strength of plate per square inch . . .	19·55		23·2		19·35	

The rivets for the butt-joints C were much in excess of the usual proportion, but it was considered advisable to use the same punch and pitch as was used for the lap-joints B, so that the plates for both joints should be placed in the same condition to start with.

The Board of Trade based their calculations on an ultimate tensile strength of 23 tons per square inch for boiler plates, but this was much too high for thick plates. The Admiralty specified for 21 tons per square inch, but they tested the plates and rejected all that fell below this standard. By bringing the above experi-

ments to the Admiralty standard, the following results were obtained :—

——	Lap A.	Lap B.	Butt C.
Size of plate	Inches. 9 × 1	Inches. 9 × 1	Inches. 9 × 1
Diameter of rivets.	Inch. 1·07	Inch. 1·20	Inch. 1·20
Broke through rivet-holes with	Tons. 66·72	Tons. 63·58	Tons. 102·5
„ „ „ per square in. with	11·52	11·77	19·0
Ultimate strength of plate per square inch.	21	21	21

For boilers with butt joints C, the Board of Trade rules allowed a working pressure of 3·53 tons per square inch of area between the rivet-holes, therefore the factor would not be less than $\frac{19}{3 \cdot 53} = 5 \cdot 38$. For lap joints B they would allow a working pressure of 3·43 tons per square inch, therefore the factor would not be less than $\frac{11 \cdot 77}{3 \cdot 43} = 3 \cdot 43$. For lap joints A they would allow a working pressure of 3·43 tons per square inch, therefore the factor would not be less than $\frac{66 \cdot 7}{3 \cdot 43 \times 5 \cdot 39} = 3 \cdot 6$. In this case the area of the rivets was taken, as it was less than the net area of the plate. In the butt joint C, the strain was central, therefore the reduction of two tons per square inch was no doubt due to punching the holes.

In the lap joints A and B the strain was not central, which was principally the cause of a further reduction of $7\frac{1}{4}$ tons per square inch. This was a greater loss than might have been expected, but as the four experiments on lap joints agreed so closely, he thought there was no reason for doubt. The lap joints A and B were only 62 per cent. of the strength of the butt joints C, yet the majority of boilers were made with lap joints.

As he had previously stated, the factors of safety would not be less than 5·38 for butt joints C, 3·43 for lap joints B, and 3·6 for lap joints A; because some additional strength would be gained by crossing the joints. At present he was unable to state the gain from experiment, but he thought it would in no case be great. If the cylindrical shell plating of boilers was only subjected to tension in the same way as the bottom plating of a girder, the shell plating would derive the same advantage from crossing the

joints as the girder plating; but this was not the case. In the shell plating the tension was due to pressure acting on a curved surface; and it acted with the same pressure on the weak joint as it did on the strong plate. When the tension became greater than the strength of an unassisted joint, the joint began to bulge; in other words, it assumed a curve of less radius, by which it was still able to resist the pressure; but as the pressure increased so did the bulging, until the rivets were sheared or the plate torn through the rivet-holes. This occurred long before the solid plates, with which it is assisted on both sides, attained their ultimate resistance.

The following experiments were made to ascertain the strength of circular furnaces as usually constructed for marine boilers: two furnaces, 3 feet in diameter and 6 feet long, were built up in two lengths, one 4 feet long and one 2 feet long. Each length was made of one Lowmoor plate, the ends being connected by a single riveted joint, so arranged as to admit of a true circle being kept. The ends of the tubes were flanged, and connected by rivets to each other, and to a strong boiler shell in the usual way.

They were subjected to water pressure until the weakest tube collapsed, when, after it had been shored up, the experiment was continued until the following results were obtained:—

Thickness of Furnace Tubes	Inch. $\frac{1}{4}$	Inch. $\frac{1}{4}$	Inch. $\frac{3}{8}$	Inch. $\frac{3}{8}$
Length of „ „	Feet. 2	Feet. 4	Feet. 2	Feet. 4
Collapsing pressure per square inch . .	lbs. 235	lbs. 217	lbs. 468	lbs. 390
Working pressure, Board of Trade Rules	$45\frac{1}{2}$	$27\frac{1}{2}$	81	60
Factor of safety.	5·2	7·9	5·6	6·5

From this it would be seen that the Board of Trade rules for circular furnaces agreed as closely as could be expected with the experiments, and that their factor was 6 for water pressure; but when the crowns of the furnaces were partially covered with even a thin scale, and exposed to the action of a strong fire, the factor 6 would probably be reduced to a factor 4.

It would be seen that the 4 feet lengths were only from 10 to 15 per cent. weaker than the 2 feet lengths, yet he would strongly advise the use of strengthening rings, provided they were so constructed as not to encourage deposit. He had seen the crowns of overheated furnaces brought down to such an extent that had not

the strengthening rings retained their shape, fatal explosions must have taken place. The Board of Trade rules for boilers were inconsistent in many respects, and must be revised before they could command confidence. Their strongest boilers have factors of 6, and the weakest boilers had factors of 4.

If their weakest boilers were safe, their strongest boilers involved a waste of materials. He did not wish to raise a doubt on the strength of their weakest boilers, as such boilers only furnished additional proofs that an actual factor of 4 was a safe factor. Take a boiler containing 18 lbs. of water for each square foot of heating surface, and let steam be raised to 60 lbs. pressure. With good fires and no escape for the steam, in about seven minutes the pressure would be doubled, and in about nine more minutes the pressure would be quadrupled; but if the boiler contained only 9 lbs. of water per square foot of heating surface, the same pressures would be generated in about three and a half and four and a half minutes. Such a case could not be met by increased strength of boiler, but over pressure could be prevented by keeping the safety-valves in good working order. The Board of Trade would not pass any safety-valves unless they were capable of discharging all the steam the boilers could be forced to generate at a pressure not greater than 10 per cent. above the working pressure, for which they deserved the best thanks of the public. The weakening action due to unequal expansion, and also by overheating, cannot be overcome by increased thickness of the plates. Unequal expansion could be prevented by increased circulation when getting up steam; and overheating could be prevented by keeping the boilers clean and the water at its proper level. Against the weakening action of corrosion, extra material must be provided for some parts to a very slight extent, as for instance the horizontal seams of rivets in the cylindrical shell; and for other parts to a greater extent, as for instance the stays; but to what extent such extra material was provided, was as much a matter of durability as it was a matter of safety,

For new boilers the Board of Trade rules allowed a working strain of 5,000 lbs. per square inch of net stay area, the factor of safety being 10. A screwed stay $1\frac{1}{4}$ inch in diameter over the threads, was $1\frac{1}{16}$ inch in diameter at the bottom of the threads; and when reduced by corrosion to $\frac{13}{16}$ inch in diameter it would have a factor of 6. If then $\frac{1}{4}$ inch was a sufficient addition to the $\frac{13}{16}$ inch stay, surely $\frac{1}{4}$ inch should also be a sufficient addition to a $1\frac{5}{8}$ inch stay; but the Board of Trade rules assumed that, in a given time the reduction by corrosion would be in direct propor-

tion to the diameter of the stay and to the thickness of the plate, which was inconsistent with experience.

November 20 and 27, 1877.

GEORGE ROBERT STEPHENSON, President, in the Chair.

The discussion upon Mr. HOLT's Paper, "On the Progress of Steam Shipping," occupied both these evenings.

December 4, 1877.

GEORGE ROBERT STEPHENSON, President, in the Chair.

THE following Candidates were balloted for and duly elected:—WILLIAM FOX, JAMES NINIAN HILL, DAVID FRANCIS HOGARTH, JOHN GALE JOPP, THOMAS COLTIM KEEFER, JOHN HENRY LOWE, ALAN MACDOUGALL, WILLIAM MORTON, WILLIAM COLTON PARKER, WILLIAM FURNISS POTTER, and LOUIS SCHWENDLER, as Members; LAWFORD MACLEAN ACLAND, Stud. Inst. C.E., WILLIAM RICHARD ACTON, AMBROSE AWDRY, Lieut. R.E., ALFRED BACHE, B.A., ROBERT THOMAS OLLIVIER BARBENSON, MARTIN BLOXSOM, EDWARD HENRY BOLD, ROBERT WILLIAM BOURNE, JAMES EDWARD NEVILLE BOYDELL, GEORGE JAMES COTTOM BROOM, GEORGE VAUGHAN BROWN, Stud. Inst. C.E., THOMAS COMMON BROWN, ADOLFO GARCIA CABEZAS, ALFRED EDWARD CAREY, Stud. Inst. C.E., JOHN CARLINE, CHARLES FREDERIC CLOUGH, HENRY JAMES COLES, CORNELIUS CORNES, JAMES CROFTON, Col. R.E., MATTHEW CURRY, Jun., Stud. Inst. C.E., CHARLES EUGENE DE RANCE, FEDERICO EDUARDO DUBOC, Stud. Inst. C.E., HENRY EVAN GRIFFITH EVANS, Stud. Inst. C.E., HENRY SOMERSON FREEMAN, THOMAS LINDSAY GALLOWAY, JUSTINIANO AURELIO GALVEZ, Stud. Inst. C.E., ARTHUR CHARLES GOTTO, Stud. Inst. C.E., JOHN PURSER GRIFFITH, JOHN GREEN HALL, FREDERICK GEORGE HANKIN, Col. M.S.C., HENRY GRAHAM HARRIS, ALFRED HOPKINSON, JOHN HOPKINSON, M.A., D.Sc., HENRY HOWARD, ROBERT HIGGS INCH, ALFRED JOHN INGRAM, Stud. Inst. C.E., JAMES IRVINE, GEORGE JESSOP, Stud. Inst. C.E., WARWICK HUSON JOHNSON, THOMAS ISAAC LILLEY, FRANCIS GASCOIGNE LYNDE, DAVID MANUEL, HENRY ROBERT HOWELLS MARTIN, Stud. Inst. C.E., WILLIAM JOSHUA MASON, Stud. Inst. C.E., HENRY MERRYWEATHER, LEANDER MUNRO MILLER, BOSWELL PARKINSON MILSOM, Stud. Inst. C.E., OCTAVIO