Discussion.

Sir ROBERT RAWLINSON, President, proposed that a hearty vote of thanks be given to the Author for his interesting Paper. He hoped that Englishmen would be gratified and satisfied with the statements it contained, and he should not be at all surprised to learn that foreigners would be exceedingly pleased to have the opportunity of studying it. England must come into rivalry with the rest of the world, and he did not know that secrecy in any department had ever served any State. Most certainly Englishmen could not be accused of practising secrecy in the important matter that the Author had brought forward.

Sir Robert
Rawlinson.

Mr. A. J. DURSTON thanked the members for the kind manner in which they had received his Paper. He pointed out that in Table E it was stated that the I.H.P. of 43·9 per ton of boilers was obtained in the "Speedy" on the forced-draught trial. A foot-note stated that the "boilers" included all boiler-room weights, whereas in a special Table, referred to near the end of the Paper itself, it was stated that 53·7 I.H.P. was obtained per ton of boiler with certain figures. The difference was caused by the different weights taken into account in the two separate statements set forth in the foot-notes, and the headings of the columns respectively. His object in preparing the Paper had been to place before the Institution, in a form convenient for reference, the results of trials in most of their naval ships. There had also been included the weights assigned to machinery and boilers, and the ratio of heating- to grate-surface adopted in various types of machinery during recent years. These were submitted as official records of what had been done, for the information and criticism of the members of the Institution and others, from which of course it was hoped considerable benefit would result.

Mr. Durston.

Sir E. J. REED said all he could hope to do, in immediate response to a call by the President, was to make a few general remarks with the view of indicating the lines on which some parts of the discussion at any rate might proceed. He need hardly say that he had joined most cordially in the vote of thanks which the meeting had been invited to give to the Author for this Paper. The Navy of this country, as the Paper well showed, was the source of enormous effort, and of vast experience in ship-building and marine engineering; and he had sometimes regarded it as

Sir E. J. Reed.

Sir E. J. Reed. a great misfortune that the heads of the technical departments of the Admiralty were so greatly pressed with public work that they could hardly do either themselves or their professional brethren justice, because of lack of opportunity of placing their work fully and clearly before the profession. He had been at the Admiralty at a time when the work of the department must have been light indeed compared with the labours of to-day; and when he thought, as he sometimes did, of the mass of responsible work which his friends Dr. White and the Author had had to do during the last few years, at the same time remembering the amount of administrative work demanding their daily attention in the management of the British Navy, he wondered that they could ever find sufficient time and freedom of mind to come forward on such occasions as the present. The Paper was an exceedingly valuable one. The Institution would have been grateful to the Author if he had merely made it a record of facts; and must be much more grateful for the inferences and reflections with which the Paper concluded. There were some things in the practice of to-day that he did not fully understand, and he would be gratified if the discussion on the Paper, which he could not help thinking would be very full and extensive if time could be allowed for it, should range over questions which were of a public and important character; and should not take a turn, which such discussions frequently took, into advocacy and descriptions of the inventions and schemes of individuals. One thing he would like to hear discussed was the relation between the diameters of the high- and low-pressure cylinders, in regard to which there was in the Navy a very great diversity of practice. The Author had given excellent reasons and explanations for some of the diversities, but he confessed that whether he regarded the statements of the dimensions and the proportions of the machinery of Her Majesty's ships, or whether he dealt with outside practice, he was sometimes puzzled to account for the great differences prevailing between the ratios of the high- to the low-pressure cylinders in modern triple-expansion engines. In some cases the ratio was stated by the Author as 1 to 2·37, and in many cases it was more than double that amount. He did not know whether his figures were quite right, but he had quoted them to illustrate the great range of practice that existed. It appeared, roughly speaking, that with a given boiler, producing a given quantity of steam at a given pressure, there must be a best practice in respect of the apportionment of the dimensions of the cylinders in which it was expended.

He had had occasion lately to consider the matter in connection Sir E. J. Reed. with actual engines for ships, and would therefore like to hear that question discussed, and to know why it was better in some cases to give the low-pressure cylinder double the ratio that it bore in other engines to the high-pressure cylinder. He wished to refer to one remarkable point of progress. He remembered well what a great step it was thought to be when the late Mr. John Penn, in the machinery of the "Bellerophon," undertook to have a piston-speed of 600 feet per minute. Something like that or a little more had first been used, but now piston-speeds of over 900 feet per minute were employed. Reference had been made by the Author to the fact that in designing vertical steam-engines for Her Majesty's Navy the height was limited because of the desirability of avoiding exposure of the machine. Apart from that consideration, that fairly raised the question whether it was much better or not, if it could be done, to obtain that high speed of piston with a long stroke, and a moderate speed of revolution; or whether there was any great disadvantage in getting it, as it was obtained in some of the cases quoted, with a very short stroke and a very high speed of revolution. He noticed that some of the horizontal engines mentioned in the Paper had a piston-speed of something like 840 feet per minute. He was willing to avow his ignorance as to the advantage or otherwise obtained by the high piston-speed with a greater or smaller length of stroke. He knew some of the obvious advantages of the long stroke, and some of the obvious advantages of the shorter stroke, but he would like to hear the question discussed from a more philosophic point of view, so as to set up a standard of the best, from which necessity might cause a departure one time this way and another time that way, aiming not only at attaining good results but also other objects which ought to be pursued. He wished to make a passing remark in memory of two deceased engineers; one, the late Sir Joseph Whitworth, who, before hollow shafts for marine engines existed, frequently conversed with him as to the desirability of producing them. He would also like to refer to the late Dr. Kirk and to the important part he played, as many members would know, in the introduction of triple-expansion engines, in devising proper standards for supporting the cylinders of engines of that type. In so doing, he rendered service of the most important character, and, in fact, in these particulars might be said to have led the way to the improvements which had been adopted. One or two observations in the Paper which he did not quite understand appeared to invite a little further discussion—

Sir E. J. Reed. for instance, as to what had regulated in all respects the question of weight of machinery and boilers in relation to the power to be developed. Attention had been directed by the Author more than once to the fact that certain sacrifices had been made on account of the necessity in certain vessels of keeping station for a long time abroad, and of avoiding the necessity for repairs. That was, no doubt, a consideration to have in the mind; but he would like to know, more particularly if the information could be obtained in the course of the discussion, how far that had operated in varying the designs of the machinery and boilers, because here again there must be for engines something like a typical standard of weight for a given I.H.P. He would like to know how that weight was increased or diminished, and particularly how it happened that in war-ships intended to keep foreign stations, there was any greater necessity for simplification or durability than might arise in line-of-battle ships when engaged in a European war, not exactly in home waters, but in the Mediterranean or other places. The question was one of very great importance, and was deserving of further consideration. The remark had reference to the cases of the "Barfleur" and "Centurion," in which there was less saving of weight in the machinery than in many of the other vessels. He was not suggesting that the course taken had not been a perfectly wise and proper one; but it was one that would bear a little further explanation and justification than had been afforded. The Paper was one of the greatest possible value to the Institution. He had frequently experienced considerable difficulty in obtaining information of an extensive character of the very kind embodied in the Paper and contained in the Tables; and the Author had done himself great honour in the explanations he had given, and the careful and proper spirit in which he had discussed them. For instance, in regard to the case of the water-tube boilers, a subject which had excited a great deal of attention and discussion, the Author had in a few statements apparently given the cream of existing knowledge. He did not know whether that would prove to be so. Other speakers might doubt or question some of the points; but, so far as he knew anything about the question, the inference which the Author had drawn from recent experience in connection with these boilers seemed to be perfectly sound and good. He hoped that before the debate closed the present position in regard to the question of forced draught would be defined a little more exactly. It had been explained by the Author that one of the principal troubles arising from its intro-

duction had been overcome. If that were so, and no remaining troubles of importance were mentioned, he would like to know what there was to prevent ships that were being built to develop an enormous forced draught, when necessity arose, from doing it under trial or at any other time. There might be reasons not known to him, but it was a matter of very great importance, because in considering the capabilities of the Navy, and considering the practice of the Admiralty as being worthy of more or less imitation, he would like to know—at least he continually found himself wishing to know—exactly the state of the question with regard to forced draught. He asked the question the more readily as it contained no kind of reflection upon the Admiralty or upon the Author. In fact, he thought the Paper showed in a very remarkable manner the great professional courage which had been displayed by the Admiralty in connection with marine engines during the tenure of office of Dr. White and the Author at the Admiralty. He took as a single instance the application of the Belleville boiler to such ships as the “Powerful” and “Terror,” which formed a striking example; but there were a great many others. They had known perfectly well that had they adhered to a single type of boiler or of engine, and pursued in a too conservative spirit one form of practice, they would have been exposed to a thousand criticisms, not only by the inventors, who were ready to criticise anybody and everybody, but by the general public, who took an interest in their affairs. He did not think anyone could read the Paper, still less study it at their leisure, without coming to the conclusion that the Admiralty had shown very great courage. It was not a light thing, dealing with such an immense service as the British Navy, to introduce great novelties and run the risk of hostile criticism that followed very often upon such introductions. These risks had been run in a very proper and becoming spirit, and he was delighted to have the opportunity of returning his thanks with those of the rest of the members to the Author, not only for the Paper placed before them, but for the enterprising spirit which he had imported into the management of the marine engineering department of the Navy.

Mr. A. F. YARROW observed that the Paper dealt with a period which would always be remembered as one in which a great advance had been made in marine engineering; and comparing the results obtained with what had been possible only a few years ago, it would be admitted that the improvements in marine practice which had taken place were as striking as during any period since the Institution was established. At the present time a horse-power

Mr. Yarrow. was obtained with a weight and within limits of space which but a few years ago would have been considered impracticable. Looking carefully into the causes which had led to this advance, with a view to studying in what direction future advances might be made, it would be seen that they must be attributed firstly to the much greater speed of piston now made practicable, by the reduction of the weights of the moving parts and by the proper balancing of all reciprocating parts. As an example he would here mention that the piston-speed in some engines was now as high as 1,200 feet per minute, indicating as much as 4,000 HP. The advance which had been made was, secondly, due to the use of materials of greater strength; thirdly, to the adoption of an increased working-pressure; and, fourthly, to the recent development of the water-tube boiler to replace that of the ordinary marine type. It was, therefore, not unreasonable to assume that if, in the future, the directions pointed out in the past were followed, a still further advance would probably be secured. The introduction of manganese-bronze for many of the parts had led to great reduction in weight when substituted for cast-iron, their relative strengths being in the ratio of about $3\frac{1}{2}$ to 1. One conspicuous advantage of the adoption of this material had been found in the case of screw propellers, for which not only reduced weight was an advantage, but the exceedingly smooth and true surface which was obtained increased the efficiency. In this respect copper alloyed with aluminium seemed to promise an even superior result. No doubt, in the future aluminium might be looked to as enabling a further important reduction of weight to be made; and aluminium alloyed with nickel, made in the United States, had great promise. With the cost of aluminium still further reduced, there was doubtless a wide field open for its application. Pistons, piston-valves and other moving parts were already being made of this material. Regarding steel, a reduction of weight might be obtained by the use of steel of a higher tensile strength than customary in marine work, which, however, did not possess so great an elongation as the softer material now in use. He believed that a reduction in elongation would not result in any injurious consequences, if not carried too far, with steel as at present obtainable, although formerly it was doubtless very necessary. He mentioned these points as showing the direction in which a reduction of weight and possible advance was at the present time obtainable. In regard to water-tube boilers, it was a remarkable fact that many designs of that type of boiler resembled very closely what was done many years ago, and had been recently brought to notice

in the interesting Paper read by Sir Frederick Bramwell at the last meeting of the British Association.¹ At that time, however, engineers had not the excellent materials now available, which might perhaps account for this class of boiler not having found favour until recently. It would be admitted that the action of the Admiralty, at the instigation of the Author, in taking the lead in introducing water-tube boilers into the Navy, although no doubt many failures might be experienced at first, would be regarded in the future as a wise policy, giving as it did official sanction to what represented an important advance.

Mr. J. I. THORNYCROFT considered the Paper to be of great value, because it not only showed what the present practice of the Navy was, but also gave an insight into the working of that practice; it showed the advantages which had been derived by particular arrangements, and also illustrated the defects which had shown themselves in the machinery at present in use. In the machinery of war-ships that part of them was being considered which was intended to make them quick, and to give them the mobility which was so necessary, and the importance of which was being more and more felt. He believed the success which had attended the Japanese Navy in the far east had been to some extent due to the superior speed of its ships, and the question of what could be done to increase the speed of ships must be considered most attentively. To obtain high speed in war-ships, not only must the engines and the boilers be light, but no unnecessary fuel must be carried. The result of the examination he had made into the Paper had led him to the conclusion that in seeking to make the machinery light they had perhaps sacrificed too much in the way of economy of fuel. A point the importance of which had been called to mind some time ago by Mr. Normand, of Havre, was the influence of the reduction of weight in one part of the vessel on all the others. It had been said that a little weight here or there did not matter; but any weight put into one part of a ship required an addition in all other parts; it meant carrying more fuel and making a larger ship. The larger the ship the larger were the engines required to drive it, and another small addition to the fuel had to be considered. It had been stated by Mr. Normand that any addition to one part meant more than four times that addition in the complete ship. Mr. Thornycroft had come to the conclusion that no definite rule could be laid down for this ratio; it depended partly on the rate at which the resistance

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¹ Report, British Association for the Advancement of Science, Oxford, 1894.

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of the ship was augmented, because by increasing its dimensions the ship was made more economical to drive. In that case an addition to the weight would perhaps not make so great an addition to the ratio by which the weight of any part had to be multiplied in considering the entire addition to the weight of the ship. On the other hand, with a ship which actually became less economical to drive as its size was increased (which under certain conditions was also possible), a different result was obtained. The reduction of weight had been sought in the engines, but he thought, in examining what had been done in the Royal Navy, it would be found that that had been worked down to a very fine point, so that much more could not be done in that direction. Again, in studying the importance of economy of fuel, the radius of action should be taken into consideration. If the radius of action of a ship was intended to be long, then the fuel became a very large element, and economy in consumption was most important. In that case it was advantageous to use a ratio of cylinders in the engines much larger than the ratio of cylinders in a vessel which was only intended to work to a small radius of action. In regard to the subject of high-speed launches, he had read a Paper some years ago before the Institution showing that the number of revolutions of the engine was a most important factor in the weight of the engine; in fact, it might be said that a good engine would almost develop power in proportion to its rate of turning; but of course many parts of the engine, such as the condensers and other parts, were not changed by the rate of turning. The surface depended upon the amount of steam used and was not changed by the rate of turning. But the source of gain in increasing the rate of turning was very limited, and was largely governed by the requirements of the propellers. If it were convenient to use a large number of small propellers, in that case the more rapidly moving engines might be used; but at present he believed that not more than three screws had been used, except in the case of the "Livadia," which had not been very successful. Two screws seemed to be the usual number employed, and in the engines of large ships the rate of turning seemed to be limited to something like 100 per minute, or rather more, whereas in small ships 200 or 300 revolutions had been obtained. Comparing the practice in the merchant marine with that in the Navy, it being important to get the highest economical results in the merchant marine, a larger ratio between the high- and low-pressure cylinders had of course been used, and the boiler-surfaces were also larger. In the Navy the great step

that had been made appeared to be in the change of the boilers; in the engines there did not appear much to be done. An examination of the Tables in the Paper showed what had been done with tank-boilers. He would divide tank-boilers into two kinds—the locomotive and the cylindrical. He did not think cylindrical boiler was quite a good description. It was a short cylinder; it had such large disk ends that a drum would, he thought, be a more appropriate name. The amount of surface to be stayed in the so-called cylindrical boiler was very extensive; the internal combustion-chambers retained much of the form of tanks put in the original form of boilers where the boiler was fitted to the ship so as to take up the room, being put sometimes against the outside of the ship and stoked in the middle; the corner was cut off and it fitted into the ship, the pressure not being a consideration. But as the pressures increased in the use of the marine boiler it became necessary to make it circular. Still, there were those large flat ends left which were all stayed, and the internal chambers also required to be stayed. One point to which he would call attention later was the great weight of the present form of boiler, which was due, as he had pointed out, to the fact that in the ordinary marine boiler there was a strong envelope, which contained not only the water and steam which must necessarily be within the boiler, but also contained the fire and the gases which need not necessarily be within it. That was one cause of the great weight of the marine-boiler. The present form of boiler now appeared to be worked to its limit. It would be seen from an examination of the Tables in the Appendix that the amount of heating-surface per HP. had been decreased pretty uniformly to about 1·7 square foot. There were exceptional cases in which it was less than that, but the result generally was that the Table was incomplete, and there were numerous examples, especially in the vessels of the "Sharpshooter" type, where the particulars for forced draught were absent. The Paper gave ample evidence that the boiler had been worked to its limit. The tubes began to leak, and when the boiler was made long, to save the weight of some of the disk ends, trouble was given with the leaky shell; and it was therefore found best to cut the boiler in two and protect it from those strains which took place owing to the cold bottom of the boiler. Perhaps it was not quite cold, but the bottom of the boiler did not rise to the temperature of the other parts. It was, perhaps, worthy of remark that if an ordinary Galloway boiler was fitted up without a flue running under it, it would soon leak. It was necessary to take some fire under the boiler to keep the bottom warm. The practice in the

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Mr. Thornycroft.

Royal Navy had been to cut down the weights as far as possible, and he had come to the conclusion that more heating-surface was desirable. He thought it evident that some new departure was necessary, and he was glad to see that that new departure had been made. Experiments had been made with the Belleville boiler of the "Sharpshooter." That was a boiler in which the fire was external to the strong envelope. It was considerably lighter than the drum-boiler, and a little lighter than the locomotive boiler; but it had quite as large tubes. The surfaces, however, he thought, were not sufficiently divided. Although the step made was in the right direction, it was not sufficient; it was only taking partial advantage of what could be done. It was perhaps true that when the experiment had been made, and when the "Powerful" and the "Terrible" had been arranged to be fitted with the same boilers, the available knowledge did not justify any further step. He thought, however, that he could show that the Belleville boiler was too heavy. That led him to a consideration of the comparative weights of different boilers. Very valuable information could be obtained on the subject from the Paper, but it was not all comparable on the same terms, because in the Table given in the Paper itself it would be found that boilers were compared without the weight of some of the fittings, the chimneys, and other parts, whereas the ash-hoists and all the engine-room fittings connected with the boiler were included in the Appendix Tables. A little correction was required with regard to the figures given for the "Speedy," the "Daring," the "Ferret," and the "Hornet." In the figures for the "Speedy" the total surface of the tubes was given. It was unfortunate that the total surface of the tubes had to be paid for, but it was not all available as heating-surface. In fact, part of the tube-surface in the boilers of the "Speedy" constituted the external surface of the boiler, and it was like considering part of the shell of an ordinary boiler to look upon it as heating-surface. With regard to the "Daring," there was a clerical error in the HP. The HP. of the three hours' trial was 4,409. The weight of the boiler wanted a little correction, he made it 47.7 tons. Taking those figures for the HP. and the weight, he deduced that the boilers in the "Daring" gave $92\frac{1}{2}$ I.H.P. per ton of boiler. The "Ferret" was compared on the same terms as the "Daring," and as a comparison was made of the relative values of the boilers, the "Ferret" having feed-heaters, a little correction must be made; because the effect of feed-heaters taking heat from the steam after it had passed two of the cylinders was really to add to the boilers, and the

additional weight of the feed-heaters, he thought, should be added to the boilers. He was sorry to bring down a rival boiler in value, but he thought that it was fairly brought down to 84 I.H.P., as compared with $92\frac{1}{2}$ I.H.P. It had been thought that results of that kind could be obtained with the drum or the locomotive boiler, but he thought that must be a mistake. In regard to the relative values of different boilers, it was convenient to consider the weights of the surfaces, because the measure of a boiler was the amount of heating-surface it provided for boiling water. Considering the different boilers mentioned in that way, he found that the weight of the drum-boiler with all the fittings amounted to 0.027 ton per square foot, and the other form of tank-boiler, the locomotive boiler, to 0.020. Taking the weight of the boilers in the "Speedy," it was a curious coincidence that their weight per square foot of surface was exactly the same as the difference between the weights of those boilers; in other words, it was only 0.007 ton per square foot. The figure for the "Daring" appeared to be 0.006, but that was neglecting the weight of the funnels and certain other fittings which were included in considering the ships. In the case of the "Sharpshooter," in which the weight of the Belleville boiler was considered, the figure was 0.016 ton. That was less than the locomotive, but more than twice that of the "Speedy," and the weight per foot of surface of the "Speedy's" boilers was about a quarter of the weight per foot of surface of the drum-boiler, taking the mean value as given in the Paper. A Paper that had been read by Sir Frederick Bramwell before the British Association,¹ was a most appropriate one for the present time, and showed that when engineers, some years ago, were put to the very difficult task of making an engine run on a common road, which was far more difficult than on a railway, they had been driven to use a light boiler, and they had taken the right step in highly dividing their heating-surface. Some of them had used water-tube boilers and others had used modifications of other boilers. But amongst boilers that were pressed very hard it was worthy of remark that the boiler that gave the most trouble was a stayed-surface boiler which brought discredit to the other coaches. He believed it was satisfactorily proved by experiments made on tubulous and ordinary boilers that the effect per unit of heating-surface was about the same. That being the case, the conclusion was reached that the weight of boiler to do equal work depended on the weight of its surface, so that the figures he had mentioned

Mr. Thornycroft.

¹ Report, British Association for the Advancement of Science, Oxford, 1894.

Mr. Thornycroft. gave an indication of the weight that must be expected for doing the work required. He would now make a comparison of endurance under forced draught. It had been stated by the Author that boilers of the Thornycroft water-tube type would not work with salt water. He might mention that one of their boats had made a journey across the Atlantic largely with salt water and that no known damage had resulted. The boat had started with fresh water, and had not used any make-up from the distiller, but had taken it all from the sea. In comparing the Thornycroft boilers with those of the drum type under forced draught, a very great contrast had been found. He thought it was a fact that the drum-boiler usually failed sooner or later under forced draught. It failed if much grease got into it, and it would not stand the quick raising of steam. Changes of the rate of working were almost fatal to it, and it suffered from being cooled down. The question of salt water was perhaps a little doubtful, but in regard to the other things there was no comparison between the two boilers. With the boilers of the "Daring," trials had been made for more than six months, and he was glad to be able to say that after very hard work they had not cost a penny for repair. With reference to forced draught, he had come to the conclusion that, as the Author had pointed out, it did not much matter how forced draught was produced, the effect being very much the same. He believed that forced draught was fatal to tank boilers, and that very tall chimneys were sometimes troublesome. In considering boilers for a particular ship it was important not only to know what power they wished to develop but what was to be the radius of action. The radius of action must have an influence in such consideration, and he thought that for long voyages, for great radius of action, ample heating-surface was required, and forced draught would not be wanted. For large ships water-tube boilers might be made to give ample steam with much greater economy than was now obtained and without forced draught. In the case of small vessels with short radii of action and very high speeds, forced draught was most essential. In fact results could be obtained by it which were quite impossible without it. There had now been extended experience with the water-tube boiler with small tubes in the "Geyser," which had been considered by the Author to be liable to prime. In the "Geyser" special precautions had been taken to avoid priming, but he was sorry to say that Captain Neilsen did not wish them described; it might be mentioned, however, that a reservoir was used besides the upper vessel of the boiler, and Captain Neilsen had said that under no circumstances had he

experienced any trouble with priming. Mr. Thornycroft's firm had made propelling machinery for a life-boat in which a water-tube boiler was used, and the results obtained had been most satisfactory. The boat was exceedingly short, and had gone out in very rough seas. The man who had accompanied it described it as standing on end. That, perhaps, was not quite true, but he could quite believe that the boat was in a position which was inconvenient for the boiler; but they had had no trouble with it. The experience with the "Speedy" had been most satisfactory, and the economy of fuel he believed would be found to be greater than in any other ship, without special precautions being made. The cylinders in the "Speedy" were not steam-jacketed, whereas some of the vessels in the Navy had steam-jacketed cylinders, and perhaps a larger ratio of expansion. The "Speedy" had the advantage of a higher pressure than the other vessels. With that exception the "Speedy" was at a disadvantage. With reference to the "Sharpshooter," he believed that tubulous boilers were right, and that the Author was justified in saying that those boilers would stand for a lengthened period without trouble. That would be a great improvement on the rest of the "Sharpshooter" class. A number of boilers had been built having small water-tubes, in which other materials than steel had been used, and in which the circulation had not been, perhaps, as good as it might have been. He thought it was proper for the tubes to deliver above the water-level, as in that way a more steady circulation was obtained. Some of those boilers with tubes of copper or brass had given trouble, and tended to do damage to the cause of the water-tube boiler. In the German Navy that type of boiler had already been not only proposed, but was being now introduced in a ship of 4,800 HP. The boilers were of amply sufficient power for their work, and of very much less weight than would be required in the ordinary way. He considered that for the Navy the drum-boiler had been improved to its utmost limit, and that no further development could be made. The particulars of the boilers required to be considered for each case, and no general rule could be laid down for the ratio of cylinders with a particular boiler as suggested by Sir Edward Reed, but he thought the radius of action of the ship should be considered in reference to that question.

Sir FREDERICK BRAMWELL, Past-President, asked whether, in the comparisons made by Mr. Thornycroft between different boilers, he had in all instances included water up to the working-level, and also the casings to the water-tube boilers, and the cleading of the so-called tank boiler.

Mr. Thornycroft.

Sir Frederick Bramwell.

Mr. Thornycroft.

Mr. THORNYCROFT replied that he had included both particulars.

Mr. Sampson.

Mr. JOHN SAMPSON thought that it would be interesting to know the reasons which had induced the Admiralty to adopt steel in place of iron for the tubes of boilers in H.M. ships. He had heard many eminent marine engineers express a strong opinion that much of the trouble experienced with leaky tubes could be traced to the employment of steel tubes for boilers in the Navy. Particulars had been given by the Author of sister ships fitted with similar engines and boilers, some with iron and others with steel tubes. It would be of interest to know what difference, if any, had been found in actual practice between iron and steel tubes, especially as regards leakage when steaming at full power, or what consideration had led to the adoption of steel tubes exclusively for war-ships. It had been further stated by the Author that air-pumps were in all cases worked off the main engines. It had occurred to him that much power was wasted in working the large air-pumps attached to marine engines, especially those running at high speeds. It would appear that, provided there were no leaks in a condenser, the work required of an air-pump was very small. He had particulars of trials of the U.S. cruiser "Columbia." The main machinery was fitted with separate vertical direct-acting air-pump engines; and, at full speed, the main engines indicating about 18,000 HP., and making 131 revolutions per minute, the air-pumps were worked at an average of only fifteen double strokes per minute, maintaining a vacuum of 25·6 inches of mercury. The ratio of the volume swept by the air-pump bucket, at the speed mentioned, to that of the low-pressure cylinder was as low as 74·4 to 1. The total HP. of the main air-pump engines was 56·3, or, in other words, about $\frac{1}{3\frac{1}{2}}$ of the total I.H.P. of the main engines. That appeared to him to be a step in the right direction, as the air-pumps could be made to work by a very simply arranged direct-acting engine without crank-shafts. They were noiseless; and they worked at such low speeds that there was practically no wear and tear. In the case of a twin-screw ship two would require to be fitted, the pipes being connected, so that in the case of one breaking down the other pump could do the work for both main engines. He was aware that separate air-pumps had been tried; but perhaps the conditions under which they were then working were somewhat different from those which formerly obtained. It might be that a single-acting air-pump, connected by beams and links to the main engine, did not require much power to drive it; but in practice he believed it did; for instance, the engines of the "Columbia" would require

air-pumps, according to the usual naval dimensions, of about 35 inches in diameter and 18 inches stroke; and, supposing the pumps were disconnected from the main engines, steam-cylinders were added to the pump-rods, and those 35-inch pumps and beams were driven at the rate of thirteen double strokes per minute (that was, at the same speed as main engines), the indicator cards taken from those cylinders and compared with the cards from existing engines which only made fifteen strokes per minute, would show that a considerable amount of valuable power had been uselessly expended. With the high speeds now obtaining it was desirable to simplify the main engines as much as possible, and to confine their work to driving the propellers only. With regard to water-tube boilers, he thought the Author was to be admired for the plucky manner in which he had tackled a most difficult question; but he might go even farther. Having procured a boiler capable of carrying steam-pressure of between 300 lbs. and 400 lbs. per square inch with safety, it might be trusted that he would not limit the pressure at the engines to the usual 160 lbs. or 200 lbs. Without high pressure the water-tube boiler would have no reason to exist, but, having adopted it, advantage should be taken of its capabilities by raising the steam-pressure of the engines accordingly. The triple-expansion engine was found in actual practice to give better results than might have been expected from it when considered theoretically. With steam-pressure of over 200 lbs. per square inch the gain theoretically did not appear great, but it was probable that by adopting a four-crank engine, quadruple-expansion, and by balancing moving parts, placing No. 1 crank opposite No. 2, and No. 3 opposite No. 4, and using a steam-pressure of say 250 lbs. per square inch, another important stride might be made in the direction of economy of fuel and reduction of wear and tear. That appeared to be an experiment which could not be better tried than by the Admiralty, material and workmanship having now reached that stage of perfection which warranted the adoption of increased working-pressure in the engines.

Mr. J. P. HALL said he had had something to do with the Naval Defence Act, six sets of machinery for six of the vessels built under that Act, and five of those which preceded them referred to for a comparison, having passed through his hands. He was, therefore, in a position to congratulate the Author not only upon the Paper as a clear statement of what was being done at the Admiralty, but also upon the great success attained by the seventy vessels described. Five and a half years ago the Naval Defence

Mr. Sampson.

Mr. Hall.

Mr. Hall. Act had been a gigantic undertaking; it was now a marked success, the whole of the work having been marvellously well carried out in every detail. The two points which in his opinion had led partly to that success were, the great allowance of weight for the machinery, about which engineers had formerly complained, and the very ample space which the builders of the engines had had at their disposal. That was clearly put forward in the Tables and by the diagrams. In reference to battle-ships, the allowance for weights was 1,150 tons, which he thought would satisfy all engineers, and the space occupied was extremely liberal. First-class cruisers were even more amply provided for, the weight being about 1,200 tons. From Table C, second-class cruisers, it appeared that the weight varied between 714 and 813 tons. Since the "Sappho" and "Scylla" (727 tons) had been contracted for, the weights had been materially increased. In later vessels the weight allowed was 800 tons, which was practically 10 per cent. more than the weight in those bracketed E in the Table. That had been a step in the right direction. The increase in the weights was due to the subdivision of boilers as pointed out in the Paper, and he made no special objection to the additional weight in this class of vessel, but at the same time he did not despise the double-ended boiler, with three furnaces in each end and one combustion-chamber common to two furnaces, fore and aft, which had in the past served the mercantile marine and also the Admiralty perfectly well. He could assert with confidence that the "Sappho" and "Scylla" could at any time do their work with ease and safety, and, considering the air-pressure now used, he thought the weight allowed (727 tons) was a liberal one. The torpedo gunboats, Table E, formed a class of vessels in which the weights had been materially increased. In the three vessels which his firm had engaged, the "Circe," "Alarm," and "Leda," the weights had been 220 to 217 tons, say 218 tons, and in the case of other vessels the weights had been as low as 207 and 208 tons. To reduce the weight of these engines to 207 tons was a step he would not like to take, and he considered that 220 tons was a fair and reasonable weight. The only reduction which he could suggest was on the boilers, which had been made to Lloyd's requirements; for he thought that, with the supervision and care exercised in the manufacture and working of boilers in the Navy, something less might suffice. During the last five and a half years his firm had had to do with all the classes of vessels referred to, and he was pleased to say that the design and construction of the machinery of each individual vessel built under the Naval Defence

Act had been amply well carried out. Indeed, the programme Mr. Hall. of the Act had been in his opinion a marked success in every way. There was one point on which he did not agree with the Author's conclusions, viz., that in reference to the application of the Martin system of induced draught to the "Gossamer." Referring to leaky tubes, it had been stated by the Author that as regards absence of leaky tube-ends, no superiority could be claimed for induced draught, and that the formation of scoriæ at the tube-ends apparently occurred to the same extent with both systems. For himself he believed in induced draught, for which he thought there was a great future. The "Gossamer," however, might not have been a very good case in which to apply it. He believed that the tubes had been severely punished by forced draught before the introduction of induced draught. With regard to ferrules with induced draught he thought they should not be used, his impression being that with induced draught the tubes would be very much more effective without ferrules, and that this would have been especially so in the case of the "Gossamer," the vessel having small tubes which were further reduced by fitting the ferrules. By reducing the diameter of the tubes, the ferrules prevented the free entrance of the flame, impeded the flow and held the scoriæ, which otherwise would have passed as dust up the chimney. He hoped, therefore, that the Author would postpone coming to any definite conclusions on the subject until he had had the opportunity of trying induced draught upon a new boiler without the ferrules. Engine-builders had hitherto complained that they had not had sufficient latitude given to them by the Admiralty. He remembered that, when the Boiler Committee sat, the enquiry to many had been made whether engineers had a sufficiently free hand. Evidence had now been given that they had a free hand. Battle-ships had been described in the Paper of various classes, including five ships of the same size, the "Gibraltar," "Royal Arthur," "Ramillies," "Crescent," and "Royal Oak," as shown on the diagrams, with cylinders of the same diameter and stroke, but in other respects no two alike. He felt quite sure that engineers would be satisfied with the free hand they now had. The Admiralty also would benefit by it, obtaining, as they would, the experience of various engineers throughout the country. Reference had been made by Sir Edward Reed to what had been done twenty years ago by the late Mr. John Penn, and to a piston-speed of 650 feet per minute having been obtained. Mr. Hall had since ascertained that nearly a quarter of a century ago the "Sultan" had been fitted with trunk engines, with cylinders 127 inches in diameter, and

Mr. Hall. a stroke of 4 feet 6 inches, running at 73 revolutions per minute, giving a piston-speed of 657 feet per minute, with an I.H.P. of 9,500, the maximum on trial being from 9,500 to 9,600. The fact of nearly 10,000 HP. having been transmitted through one shaft twenty-five years ago deserved to be recorded.

Mr. Gross. Mr. F. GROSS had no intention to criticise any portion of the results relating to boilers chronicled in the Paper, but wished to place on record the results of trials of a new system of draught which promised to be of considerable use in the immediate future. The original experimental plant consisted of five single-ended marine boilers, part with plain tubes, part with "Serve" tubes, which could be worked with natural, Martin mechanical suction, or Howden forced draught. The results had shown (1) that suction draught with all air-pressures negative was preferable to the positive pressure of forced draught, because the boiler was heated more uniformly and not so severely locally, the action being that of largely increased natural draught; (2) that, taking all the circumstances into consideration, a cylindrical boiler of the same size and with draught of equal value could not, with plain tubes, be as economical as one with Serve tubes; and (3) that the cooling of the gases after they left the boilers, necessary for the sake of the exhausting fans, could be used for heating correspondingly the bulk of the air required for combustion. The recognition of those facts had led to the combination known as the Ellis-Eaves system, consisting of suction draught, heating the air by the waste gases, and using "Serve" tubes and retarders. The installation on those lines of two boilers of the same dimensions as the earlier experimental plant had proved anticipations of them to be correct, and the number of boilers had gradually been increased to ten. In daily work the average combustion in the boilers was 35 lbs. per square foot of grate 5 feet 8 inches long, and the average maximum power of combustion was 45 lbs. Some boilers could burn as much as 60 lbs. on the same size of grate. At a combustion of 30 lbs. to 35 lbs. per square foot of grate, the evaporation from cold feed with ordinary South Yorkshire coal was 9 lbs. of water actual or $10\frac{1}{2}$ lbs. from and at 212° F., at 45 lbs. per square foot it was $8\frac{1}{2}$ lbs. and 10 lbs. respectively. With best South Wales coal the results were $\frac{3}{4}$ lb. better in each case. Any kind of coal could be burnt without smoke. With a combustion of 45 lbs. per square foot of grate, the temperature of the gases on reaching the fans did not exceed 450° F., and the air was heated to 300° F. The first two boilers were now three and a-half years old, the next

two were two and a-half years old, and there had been no trouble Mr. Gross. with fans and fan-engines, furnaces, grates, tube-plates and the tube ends, which were entirely unprotected. The system had been used in two sister ships, named the "Perthshire" and "Buteshire," built by Messrs. Hawthorn, Leslie and Co., Newcastle, of over 10,000 tons displacement, with triple-expansion engines to develop 3,000 I.H.P. Each had two single-ended main boilers 15 feet 6 inches in diameter and 12 feet long, with six Purves flues of 3 feet 9 inches inside diameter, with a grate-area of 127 square feet, heating-surface in the boilers 4,770 square feet, and working pressure of 160 lbs. per square inch. At full power each furnace therefore had to develop 500 I.H.P. Those boilers, with their water and the draught installation complete, including funnel, weighed 228 tons, and could easily give and maintain the 3,000 I.H.P. of the main engines. The usual work was to develop about 2,500 I.H.P. with the main engines, and on the return voyage the main boilers had also to supply the steam for extensive refrigerating machinery. On arrival in Australia the boilers were cleaned, and they had then to be continually under steam, whilst collecting the meat at the various ports, bringing it to London and discharging it there, for about 90 days. In port the boilers worked chiefly with natural draught, for which they were perfectly suitable, having Serve tubes of $3\frac{1}{4}$ inches outside diameter, and good funnel height. On the outward voyage the work had equalled therefore 11 I.H.P. per ton of boilers, or nearly 20 I.H.P. per square foot of grate. On the homeward voyage the evaporation, being equal to at least 2,750 I.H.P. of main engines, was nearly 12 I.H.P. per ton of boilers and 22 I.H.P. per square foot of grate-surface. At the full power of 3,000 I.H.P. that was equivalent to over 13 I.H.P. per ton, or nearly 24 I.H.P. per square foot of grate-surface. Small coal was generally used, and could quite conveniently be burned with that system. The coal-consumption per I.H.P., including that for the fan engines, averaged 1.35 lb. for Newcastle small coal, and less than 1.3 lb. for South Wales ordinary bunker coal. At 1.3 lb. the combustion was 30 lbs. per square foot of grate. He could further point to two large new steamers, the "Southwark," built by Messrs. Denny, and the "Kensington," by Messrs. J. and G. Thomson, for the American line, of over 12,000 tons, to develop 7,500 I.H.P. with twin-screw quadruple engines, having cylinders $25\frac{1}{2}$ inches, $37\frac{1}{2}$ inches, $52\frac{1}{2}$ inches and 74 inches in diameter and 54 inches stroke. The boilers were similar to those of the Australian steamers, viz., two double-ended, 15 feet 9 inches in diameter

Mr. Gross. and 21 feet 8 inches long, and one single-ended, 15 feet 9 inches in diameter and 11 feet 3 inches long, grate-surface 383 square feet, heating-surface 12,500 square feet, four Purves furnaces, of 3 feet 4 inches inside diameter, in each end, and a working pressure of 200 lbs. per square inch. Both these vessels on their voyages west had developed about 7,500 I.H.P., or nearly 20 I.H.P. per square foot of grate, which, in all cases, was 5 feet 9 inches long. Those performances were not short trial-trip performances, but were repeated results of regular long voyages, practically as certain and safe as if they were natural-draught ships with twice the number of boilers, and they compared favourably per square foot of grate with the forced-draught trial results of the present Admiralty cylindrical boilers and the Belleville boilers, although they were not yet as light per I.H.P. In considering the question of weight, it was, however, necessary to bear in mind that the steam in the ships named was produced much more economically. Based on the long series of their comparative trials, an economy of at least 10 per cent. was obtained over the present Admiralty cylindrical boilers with natural draught, and more against forced draught. Reckoning an average of 2,750 I.H.P. for a fifty days' voyage, at only 10 per cent. economy, a saving of weight of 158 tons of coal had been effected, and left the weight of boilers and coal together in favour of the "Perthshire," as on the question of weight, the result was the same as if the boiler installation complete weighed, say 70 tons with the ordinary coal consumption per I.H.P. That relation would occur in all long-voyage steamers and warships intended to carry large quantities of coal. If the "Perthshire" were fitted with natural draught and four single-ended boilers of the present size, the weight of her installation would be 145 tons greater. If those natural-draught boilers had plain tubes, they would require to burn at least 10 per cent. more fuel to give the same amount of steam. If they had "Serve" tubes, they would burn the same amount for the same evaporation. Consequently the existing installation gave the same economy with 145 tons less weight and half the floor space.

The arrangement was such that the space and weight of the boilers and coal combined could for large ships be kept below that required for cylindrical and water-tubular boilers with coal, and possessed all the advantages of suction-draught, explained by the Author, with the additional advantage of large diameter tubes, ample water and steam spaces, and the immunity from leaky tube-ends, the readiness with which steam could be raised, and the absence of all special precautions in their stoking, which

had been mentioned in favour of the water-tube boiler. In the trial of suction-draught pure and simple, leaky tube-ends had been found by the Author, but Mr. Gross was convinced that if large diameter Serve tubes, say $3\frac{1}{4}$ inches outside diameter, were used, the same immunity from leaky tube-ends and blocking by scoriæ would be obtained. The introduction of the Serve tube, with twice the amount of heat-absorbing surface, enabled the use of the same outside diameter as with ordinary natural draught. In France the Admiralty used the Serve tube entirely in their cylindrical boilers, and the lower rows of the water-tubular boilers. Some 400 locomotives were already running there with Serve tubes $2\frac{3}{8}$ inches in diameter, instead of plain tubes of $1\frac{1}{4}$ inch to $1\frac{7}{8}$ inch diameter. There was no reason for using a smaller diameter Serve tube than $3\frac{1}{4}$ inches, even for a combustion of 54 lbs. to 60 lbs., and an evaporation of 30 to 40 I.H.P. per square foot of grate 5 feet 6 inches to 6 feet long, which they can readily give on land. From the absence of trouble with the first boilers on this system, now three and a half years old, which had been subjected intentionally to the roughest treatment, it might be reasonably inferred that for endurance and life they would compare most favourably with others.

Mr. A. E. SEATON thought the Paper might be regarded as a monument of the engineering skill and enterprise of the country. The Institution was to be congratulated on such a Paper being read within its walls, since it was fulfilling its proper function of embracing all kinds of engineering, and especially those branches which were of such importance to a maritime country. The Author had done great service by epitomising the results of the ships built under the Naval Defence Act, and the more the figures in the Paper were considered the more instruction would be gleaned from them. He had not had an opportunity of studying the Paper as deeply as he could desire; but the first point that had attracted his attention was the information the Author had conveyed that at a comparatively late period of their construction certain ships had been directed to be worked at something under the forced-draught power for which they had been designed. He thought that was a step eminently in the right direction, and events had proved it to be so. He had always felt strongly the necessity of obtaining moderate economy even from such engines as those of which the Author had to direct the construction. Reference had been made by Mr. Thornycroft to the radius of action of ships, which he had understood was the distance that a ship was capable of travelling at moderate speed

Mr. Seaton. with a certain coal-supply. He did not know that the term was used with reference to performances under forced draught. He thought the Author had made a step in the right direction when he altered the settings of the valves of certain ships so that their I.H.P. was somewhat less than was expected under the contract. The wisdom of such a course had been proved by the event, because, in the case of his own ships, the I.H.P. of which had been reduced from 12,000 to 10,000, little more than 10,000 HP. had been required to get the speed that was laid down for the ship, under forced draught, with 12,000 HP. In fact, a higher speed was obtained with a considerable economy of fuel. He was sorry that more figures than the Author had quoted had not been given. Perhaps the Author did not attach the same importance to fuel-consumption as those sometimes did who had to pay for the coals. He attached considerable importance to the subject for that reason. Ships built by him had succeeded in running their trials at what might be called moderate forced draught, with a consumption of 1.69 lb. per I.H.P. in one ship, and of 1.62 lb. in the other. He did not want to grind axes, but he felt proud of that result, because he thought it was the lowest that had been attained in any ship of that class, and compared favourably with the figures given by the Author. It should be stated that the results had not been obtained by himself or by his staff, but had been furnished by the dockyard officials who superintended the trials. A little mistake had been made by the Author in his summary. The engines which his firm had made had not forged steel columns, but steel castings, and were not like those of the "Royal Arthur," but were from an entirely new design, having some of the characteristics of the other design. It would be noted that the standards and guides weighed only $22\frac{1}{2}$ cwt. against 46 cwt. in other ships. The "Royal Oak," which appeared to be the lightest, was actually the heaviest. The point was interesting, and had occurred also in the design of the torpedo-boat destroyers. It had been concluded that the lightest form of engine was that with turned steel columns. On enquiry he had found that a design with back cast columns could be made really lighter than with forged turned columns. The total weight of frames and standards had been stated by the Author as 54 cwt., and at first sight that did not appear to compare favourably with those of the "Royal Arthur," but the ships as well as the engines had been built by his firm, who had to make the seatings as well as the castings. With regard to the question of forced draught, he did not understand how any engineer could be misled by such terms as negative

and positive draught, and he did not see how the action on the tubes would be in any way different, whether the air was blown into a stoke-hole by a blower or came into the stoke-hole because the blower was sucking the contents out of the funnel. His view upon that matter appeared to be corroborated by the Author's opinion. That the induced draught system was a convenient and cheap one he freely admitted, and in 1872, when Sir Edward Reed was designing a very fast ship, Mr. Seaton had schemed a similar device for him, with the object of doing without a funnel. With regard to the air-pump question, Mr. Sampson had expressed a hope that some one other than Messrs. Maudslay would try an independent air-pump. When his firm were entrusted with works under the Naval Defence Act, they had considered the point, and he therefore knew something about the matter and could speak with some confidence. One of his first endeavours had been to work the whole of the pumps by independent engines, but, whereas there was no difficulty with circulating pumps, feed-pumps, and bilge-pumps, the utmost difficulty had prevailed with air-pumps. In the first place he had found that more space was occupied by them than was allowed. The space which had been allowed in the ships had been referred to by Mr. Hall. Mr. Seaton admitted that the Engineer-in-chief had allowed plenty of weight, but the same liberal allowance had not been made in regard to space. He had therefore found it at the outset very desirable to have an independently worked air-pump, but room for it could not be found. But there had been, however, another difficulty, viz., that the pump was almost uncontrollable. The only method he could conceive of controlling it was by the old-fashioned cataract. He need not enter into the scientific aspect of the question, but he would simply state that the air-pump was the most difficult of all to control. He had been informed that the pumps of the United States cruiser "Charleston" had been found to be uncontrollable. He remembered twenty-five years ago having seen a ship fitted with independent air-pumps by Roger of Glasgow. In those days a jet-condenser was used, and there was no uncertainty as to the amount of water obtained at each stroke. He thought the Author had acted very wisely in striking out boldly for the use of the water-tube boiler. His firm had removed the insides of a large number of cylindrical boilers to put in new ones, and they were generally found to be a great deal worse when they were opened up than they appeared to be on cursory examination. The insides of those boilers gave a large amount of trouble. As had been said in a recent letter to Mr. Seaton.

Mr. Seaton. "Engineering," there were Howden boilers, now twenty years old, which were still in good condition. He could say the same for boilers that he had had the pleasure of making twenty years ago, but not all the Howden boilers, or those made by his own firm twelve years ago, were now in existence. H.M. ships were on totally different service from those in the mercantile marine. All classes of H.M.'s ships were called upon at short notice to perform service. At any time, especially in war-time, it would be impossible to give a war-ship the necessary notice in order that steam might be raised in such time as not to injure a large double-ended cylindrical boiler of 180 lbs. per square inch pressure. The fact had been overlooked by Mr. Howden that twenty years ago boilers were made for a pressure of 60 lbs. per square inch instead of 180 lbs. He agreed with the Author that for H.M.'s ships single-ended boilers were undoubtedly better than double-ended. He also agreed with Mr. Hall that double-ended boilers had been useful in the past, and, with reasonable care, they were serviceable now. They were, however, treacherous if they were not treated properly. On the other hand, the water-tube boiler, whether Belleville, Thornycroft, Yarrow, or Babcock-Wilcox, had the quality of enduring rough usage. In a boiler in his own works, the fires had been lighted and steam had been raised in thirty-five minutes, and in another case in thirty minutes, and no harm had been done. The amount of coal consumed in getting up steam had been very small. The circulation in the boiler had commenced directly the fire began to burn, and the bottom of the boiler was as hot as the top within a few minutes of the fire being lighted. All those points were of the utmost importance in dealing with boilers for ships likely to be called upon to perform service at short notice. He did not suppose that the Belleville boiler had been adopted by the Admiralty without the fullest consideration. It had the merit of very large tubes, and he had been especially struck with one passage in the Paper bearing on that point. He thought that the mistake in both the Yarrow and Thornycroft boilers was the presence of small tubes next the fire. He thought those boilers would be materially improved if one or two rows next the fire were considerably larger than the other tubes and somewhat thicker. It was desirable to reduce the violent action in those tubes, and to prevent them from absorbing the large amount of heat that they were capable of doing, and allowing more to pass to the next lot of tubes. That was a mere matter of detail that could be easily overcome. In the case of such boats as the

torpedo-boat destroyers, one of them might be lying in a little creek, and receive orders to go on service at full speed. There would be no time for nursing the boilers, as it would be necessary to raise steam immediately. The water-tube boilers were capable of that. The locomotive boiler, with all its virtues, which he did not desire to minimize, could not compare with the water-tube boiler in that respect. Upon one set of figures given by the Author he looked with some amount of disappointment, viz., those in reference to I.H.P. obtained in the ships per foot of grate. The disappointment was that it was so small considering what Mr. Gross was doing at Sheffield, but it probably arose from a slight misconception of the facts. In H.M. service, as in every other fleet of steamships, the best fuel could not be always procured. The vessels might go to a station where the fuel had been under a burning sun for months, and what engineers called the "nature" of the coal was gone out of it, so that a great deal had to be burned to get the necessary amount of steam. If the coal were good, one half the grate-area might be sufficient. That brought him to the point that, if the grates were not made too large, there was no limit to the air-pressure that might be put on the boilers. What had happened in the past had not been due to any particular pressure, whether $\frac{1}{2}$ inch, or 3 inches, or 6 inches; the question was, what amount of heat had it been tried to pass through the tubes in a minute or in an hour. Whether the heat was obtained with a short grate and intense draught, or a long grate and a dead draught, did not signify. The question was the amount of heat it was attempted to pass in the chamber, and from the chamber through the tubes. In the case of naval boilers the introduction of a ferrule specially adapted for the purpose had overcome the difficulty. It had been very properly stated by Mr. Gross that, in order to secure success with induced draught on their system, there must be a Serve tube, because a Serve tube by its large diameter allowed ample space and ample water in the neighbourhood of the tube-plate. That was a great thing, and it was what the Author did not find in the boilers for which he was not responsible.

Mr. J. P. SYMES pointed out that in Table A of the Appendix a class of eight vessels of the "Hood" type had been mentioned, and said he should be glad if the Author would explain the statement that in that particular class there were "boilers of the single-ended return-tube type, eight in number, in four compartments, arranged back to back, against a middle line division; each boiler has four furnaces with two, three or four combustion-

Mr. Seaton.

Mr. Symes.

Mr. Symes. chambers." Water-tube boilers were coming into use; the other boilers were out of date for the very high pressure now being used. He wished to know why three classes of boilers were placed in one ship. No doubt each of them had its advantages, but it appeared to him remarkable that those three different classes should be placed in one ship. In Table B reference had been made to ships of the "Blake" type, fitted with six double-ended boilers, with four furnaces at each end leading into one combustion chamber. If the same efficiency could be obtained from boilers of these two classes, supposing the external dimensions to be the same, there was great advantage of the latter boiler over the former. There was a saving in the weight of the boiler itself, the saving in the workmanship was very considerable, and there was also a saving in the weight of the water carried.

Dr. Kennedy. Dr. A. B. W. KENNEDY wished, in calling attention to a few omissions in the Paper, to state at the outset, that he could not hold the Author responsible for those omissions, because he had no doubt if the Author could have filled up the blanks to which he was about to refer he would have done so. He might even go farther and say, although he had not had an opportunity of speaking to the Author on the matter—that he was not only sure that he would have been most pleased to give the information, but he strongly suspected that the Author was entirely in accord with him in wishing that he were able to give it. Special stress had been laid by the Author on the ratio of HP. to weight, and he had determined those quantities, or enabled others to judge of them, solely by quoting the total weight of the machinery and boilers and the total HP. obtained under different conditions. He ventured to think that this was incomplete in one or two ways. In the first instance it was obviously incomplete because the weight of the coal carried must be taken into account. A vessel had to carry not only her machinery and boilers, and the water in the boilers, but coal for a certain number of days' run, varying no doubt in different classes of ships. Taking the run approximately as ten days at such powers as were given on the last page of the Paper, it might be roughly said that the total weight of coal did not differ much from the total weight of the boilers, water and machinery. It was therefore a quantity the weight of which was of the very first importance. That opened up a very wide question, and a question with regard to which it was not at all easy to form a correct opinion or make a good comparison between different

results unless not only the weight of the machinery (using the word in the general sense), the speed of the ship and the I.H.P., but also the weight of the coal used per hour under given conditions were given. He thought that to obtain a good result they should also know the weight of the water used per hour under given conditions. Without those quantities he thought that the department over which the Author presided was working under very great difficulties indeed, because it was attempting to design, and was indeed actually designing, machinery (against which machinery he had nothing to say) with most imperfect data as to what that machinery would actually do. He could not too strongly emphasize the fact that it was really a matter of necessity to know the amount of coal and the water used per hour for a given HP. and therefore for a given speed, in order that the designers might have a secure basis to work upon. Moreover, those figures should be known separately, otherwise it was impossible for anyone to judge whether a saving could be made on the engines or on the boilers, or on both, or on neither. In 1886 a Paper dealing with marine engine design was read at a meeting of the Institution of Mechanical Engineers,¹ and he then ventured to bring forward the point he was now urging. He had been told at once that the thing was impossible, and that water and coal could not be measured at sea—certainly not water. Indeed a generous offer had been made to put a steamer at his disposal to make any measurement he liked as long as he did not attempt to measure water or to do anything so foolish. Happily he did not accept the offer, but from the discussion at that meeting originated the appointment of a Research Committee of the Institution of Mechanical Engineers, which, whatever else it did, at least showed that it was quite possible under the ordinary conditions of the merchant service to measure coal and water on board ship without interfering with the regular conditions of working. The engines tested certainly did not indicate 13,000 HP., but their HP. was at least measured by thousands, and that was no small matter. He thought that if what might almost be called a scratch company of amateurs could manage to do this under difficult and disadvantageous circumstances, there could be no physical difficulty in the way of doing it in the Navy; at least, if there was, it was time that those difficulties were overcome. He had heard it said that there was always the great difficulty of want of time. He believed he was not putting it too

¹ Institution of Mechanical Engineers, Proceedings, 1886, p. 504.

Dr. Kennedy. strongly in saying that this was not a true difficulty, because he did not think a ship of such importance as any of the vessels in question—everything connected with which was of national importance—could be considered finished and ready for service until the particulars he had mentioned were known. Except in the case of war, or some serious matter of that kind, ships should no more go away without the Author and his department knowing the figures connected with its actual economical working, than she should go away without her cylinder-cover, or the blades of her propeller. He was glad to take that opportunity of expressing what he believed was the view of many engineers, that this matter was of really vital importance; indeed, he thought Dr. White would be in great difficulties in his designing, if he had not beside him the results which he could get from experiments made on model vessels, such as he knew were now used to a large extent. Unfortunately, experiments could not be made on models as to the amount of coal which would keep the ship running at a certain speed for ten days; that had to be done on the ships themselves, and it was no doubt much more troublesome and difficult to do. But he ventured to think that until that information was obtained, at whatever trouble, and put into the hands of the Author and his colleagues, they would be as badly off, and would be working under as many difficulties in their enormously important duties, as Dr. White would be if all the scientifically-obtained information which fortunately he was able to get from models were swept away, and he had to work upon data which were as rough in comparison with his own work as the data on which the engineering department had to work, viz., the data which the Author had given so fully in his Paper, and which, from the point of view he was trying to place before the meeting, were after all incomplete.

Prof. Biles. Professor J. H. BILES hoped the Author would state the pounds or tons per I.H.P. instead of the I.H.P. per ton. He had given in the Table a column of figures with regard to the machinery complete, and also for the boilers, in the form of so many I.H.P. per ton. The boilers and the engines produced in one ship the same I.H.P., and therefore to give a figure which showed so many I.H.P. per ton for the boilers, and another figure, half the amount of the total machinery, did not give one the opportunity of seeing how many I.H.P. per ton the engines alone would be; whereas had the weight per I.H.P. been given instead of the I.H.P. per ton, the difference in the two columns of figures would give

the weight per I.H.P. of engines alone. The war-ship problem naturally suggested two points of view. First, war-ships were produced to compete with other war-ships. It was, therefore, necessary to consider what war-ship builders were doing in other countries, and Tables were accordingly wanted which would enable judgment to be made of their performance, of the risks which were being run, and of the fineness of the margins compared with those of the British Navy. There was also the other consideration, that the engine and boiler, the installation of machinery in a war-ship, formed a steam-producing plant, and it could therefore be compared with the steam-producing plant not only in other navies, but also in the mercantile marine. There were a few instances in the mercantile marine in which the development of power per ton of weight was as good as it was in the Navy; and there was the curious fact that there were many builders in the country who would produce an installation of machinery which they would put either into a war-ship or a mercantile ship. In the mercantile ship there would be very common firemen, very common engineers, who were not in any way men possessing any superior qualification. That machinery would do its work day by day. It would, for instance, run across the Channel, and work for three or four, or perhaps five or six hours, under forced draught. It would stop at the end of its journey, after having gone all the way at full speed, and it would cool down as best it could, and start again the next day, doing it all without having the reputation of giving any trouble. On the other hand, the same builders would put a similar installation into a war-ship, and it was common knowledge that those war-ships, with practically the same installation, had the reputation of not doing very well. That led to a consideration of the cause. The only difference he could perceive was that in the human element; and that again led to the consideration of what was the difference between the engineers in the Navy and those in the mercantile marine. It appeared to him that the difference could only be, that in the mercantile marine the engineer did practically as he liked on board ship, while in the Navy he was dominated by the naval officer. That was necessary to some extent for the purposes of discipline, but he thought it was a subject for the serious consideration of the naval officer whether that domination was not too great for the efficiency of the machinery—whether the calls made upon the engineer to do what the naval officer wanted him to do from a disciplinary point of view were not too great for that purpose; and whether the

Prof. Biles.

Prof. Biles. engineer officer should not have a greater independence than he had at the present time under the disciplinary domination of the naval officer on deck. He thought that perhaps there was more want of efficiency in the engineering plant of the Navy from that cause than from any other.

Dr. White. Dr. W. H. WHITE felt that naval architects had been showing themselves rather too largely in the discussion. He would not say a word but for the feeling that there were certain things that he might say that could not be well said by his friend and colleague, the Author, who had kept his Paper strictly within the lines of marine engineers' work. Particulars had been given by the Author as to the production of steam in boilers, the development of power in engines, the consumption of coal, and other matters which were of the greatest interest to those engaged in the design and manufacture of propelling-machinery for ships; but little, or nothing, had been said by the Author with reference to the utilization of power to the speed of ships, the choice of propellers, the causes influencing their efficiency, and the effect upon engine design which must arise from changes in speed and methods of propulsion. All the points which the Author had touched upon were points for the marine engineer, and it was a matter of very great satisfaction that so many marine engineers of eminence had taken part in the discussion. It was, however, a matter of some disappointment that they had not heard expressed, in a place where discussion was of the freest, and where reply was possible, some of the points which they had been accustomed to see discussed very fully in the technical press. It would have been an advantage to the Author in replying if those points had been brought into the discussion, so that he might deal, at least, with some of them. The Paper as it stood gave, as Dr. Kennedy had said, a great deal of information, but he did not think that it was the Author's intention in writing the Paper to tell all he knew; he still kept something to himself. The Paper could not have been kept within workable limits if the other policy had been adopted; and he knew that the Author would be in a position to tell Dr. Kennedy that his knowledge extended farther than would appear from the Paper itself on some of those points to which attention had been very properly drawn. The period with which the Author had dealt was one which had been most critical in the history of marine engineering. It had been a period during which he personally had been most keenly interested in war-ship design. Looking at the figures given in the Paper,

one thought of many of the difficulties and struggles, and, he Dr. White. thought he might say, some of the successes that had been achieved. In the Navy, during that time, there had occurred the extended use of forced or induced draught, a very considerable increase in steam-pressures, the introduction of the triple-expansion engine, the practical abandonment of horizontal engines in favour of those of the vertical type; a considerable increase in the rate of revolutions and piston-speed, a considerable increase in the speeds of ships, and a large economy in coal consumption. All these points appeared from the Tables, but they were all points which had an enormous effect upon war-ship design and propulsion all over the world. The Author's account of Admiralty practice represented not merely what had been done by himself as Engineer-in-chief, by his colleagues, and by his predecessors in office; but it represented and embodied the work of the leading marine engineering firms in the country, who, subject to the conditions laid down by the Admiralty, were continually producing, not merely engines, but designs for engines which were adopted in H.M. service. He thought that some of the differences which had been referred to in regard to the variety of practice in connection with engines and boilers, during the period set forth in the Tables, were only reasonably to be expected, when it was remembered that such a large number of engineering firms had been engaged in producing the machinery. He well remembered one special case—he did not say it was a strictly representative one—which occurred about twelve years ago, when the "Mersey" class, of which particulars were given in the Paper, was being designed. At that time his friend, Sir James Wright, was Engineer-in-chief, and he had adopted the course of fixing the limits of space and weight, and fixing what he conceived to be the essential conditions to be fulfilled in the design in regard to the quality of materials, the factors of safety for various parts and matters of that nature. Invitations had been sent to a number of the leading firms in the country, asking them to say what, within those limits of space and weight, they would be prepared to do in the development of power and in the consumption of coal. That invitation had been responded to by a number of firms. Their designs had been perfectly independent, and from amongst them had been selected that which was adopted for the "Mersey" and "Severn," which were amongst the first ships designed on the principle of adopting forced draught in the boiler-room. War-ship machinery, whilst it had its special features, owed very much to mercantile practice and experience—and no one was disposed to minimize that for a moment—especially

Dr. White. in regard to the use of increased steam-pressures, the introduction of the compound, and then of the triple-expansion engine. Those were only examples that might be multiplied. He thought it might be fairly claimed that the benefit had not been altogether on one side, and that the practice in war-ship machinery had also had a considerable influence upon much that had been done in the mercantile marine. As an illustration he might mention the use of forced draught in war-ships. He did not want to discuss the question whether forced draught had been carried too far or not in any particular instances, but he should like to point out that its use in H.M.'s ships had had a very marked effect upon the development of methods of assisted or mechanical draught in merchant ships during the last ten or twelve years. It was a notable circumstance that, in the statements made by Mr. Gross with reference to the development of power per square foot of heating-surface for continuous steaming at sea with the Ellis-Eaves system, results were claimed which compared very closely with the highest performance obtained with forced draught in H.M.'s ships on comparatively short trials. He thought he was right in saying that in the practical working of the Howden system at sea the development of power per square foot of heating-surface in the boilers had been stated at from $1\frac{3}{4}$ to 2 square feet per HP., which again would be seen not to compare unfairly with the maximum results mentioned in the Paper as obtained with forced draught for short periods. The point he wished to make was that the change of practice in H.M.'s ships had had a great influence upon mercantile practice, and had led many able and ingenious persons to consider the introduction of methods of assisting draught and of obtaining greater power from a given weight or size of boiler in association with economy of coal. Again, the successful employment of quick-running engines with moderate stroke in war-ships had its influence in the mercantile marine. He remembered being on the trial of the "Parisian," with the late Dr. Kirk, many years ago, when he allowed the engines to "get away," and they made 85 revolutions with 5-foot stroke and a piston-speed of about 850 feet per minute; the ship flying light and everything running at its best. In those days that was thought to be a very remarkable performance, far in excess of the condition under which ships then worked at sea. In the interval piston-speeds and revolutions had been increased, and results were now commonly obtained which, a few years ago, would have been thought undesirable or impossible. He could not help thinking that the experience of the Navy had largely

influenced progress in that direction. But while engineering Dr. White. practice in war and merchant ships had much in common, there were special limitations in war-ship machinery design which could not be got away from. It was to be remembered that war-ships were essentially fighting-machines, that they were built to carry armaments, to carry various methods of protection involving large weights of material, and the whole arrangements of the machinery had unavoidably to be subordinated to the preservation of fighting qualities. Of that there were many excellent examples in the diagrams, and it was hardly necessary to dwell upon it. From the examples of the arrangement of boilers in a battle-ship shown in the "Ramillies" diagrams, it would be seen that the stokeholds were placed fore and aft, and the longitudinal extension of the boiler-rooms was thus compressed. The explanation of that was that as she was a ship of great beam, it was possible to get an arrangement of coal and stokeholds favourably disposed in the breadth of the vessel. Before and abaft the machinery-spaces there were situated huge armoured enclosures containing the heavy guns. Every foot added to the length of the machinery-spaces in such a case involved an enormous weight of protective material, because it meant an extension of the armour to cover that length. In fact the arrangement of machinery, boilers and coal, was largely governed by the consideration of what lay above it in the way of protection and armament. There were ships in the Navy in which, immediately above the boiler- and engine-rooms, an armoured citadel stood, containing turrets in which very heavy guns were mounted, that had to be supplied with ammunition; there the engineer had perforce to accept conditions which he would be willingly free from, but it was of the essence of the design that that disposition of the armament should be provided for. Taking, on the other hand, first-class cruisers with protective decks, as in the case of the "Royal Arthur," there were greater possibilities in length, but considerably less beam than in the battle-ships, and there was the protecting deck existing throughout the length. There the best possible combination which could be made included athwart stokeholes and athwartship coal-bunkers. Going to the engine-room, it would be seen that to maintain the desired length of stroke in a vessel of moderate draught, an armoured enclosure was built surrounding the cylinders, and giving facilities for protection, ventilation, and all matters affecting the working of the machinery. Those were only instances that could be multiplied indefinitely, showing that in a war-ship the fact that she was a fighting-machine

Dr. White. governed everything that had to be done both by the marine engineer and by the naval architect, increasing immensely the difficulties of both. Criticisms had often been made upon the arrangements of the machinery and boilers in war-ships which entirely ignored that governing condition, and he ventured to say that if some of the ardent critics were themselves placed in the unfortunate position of having to meet those difficulties, they would find it no easy task to provide solutions immensely superior to those which Admiralty experience had led the responsible designers to adopt as the best under all the circumstances. He did not say that Admiralty practice was incapable of improvement; he only said that it was a very desirable thing in dealing with any piece of mechanical work to assume that the man or men who were responsible had some reason for the method to which they ultimately came, and that they did not do what had been done out of pure wantonness. There was one other fact that he desired to state. It was a popular idea that the marine engineer was a "good man struggling with adversity" when dealing with the machinery of war-ships. Adversity was personified by the naval architect: he was always pressing and limiting and saying, "No, you shall not—this is all you shall have," and the marine engineer—poor, patient soul!—never complained, but always accepted everything that was offered. That idea was of course perfectly ridiculous. In all steamship design the essential condition of success was the harmonious collaboration of the naval architect and the marine engineer. He had had the honour of serving, since he had been Director of Naval Construction, with three Engineers-in-Chief, and—he said it in the presence of the Author with the greatest pleasure—from first to last there had never been any difficulty or difference of opinion whatever between them. Every point that had arisen had been dealt with by them conjointly, and they had only the common object of producing the best vessel to meet the stipulated conditions. The first of those gentlemen he had already mentioned, Sir James Wright, a man who had lived through marine-engineering from its commencement in war-ships, and who quitted work after he had served the Admiralty forty years. During that time Sir James Wright lived for the service in which he was employed, and although he was now enjoying well-earned rest, he, no doubt, looked with the greatest sympathy on what his successor had to face and to bear. The second was his dear friend, Mr. Richard Sennett, a man with whom he had been associated from his student days to the time of his death—a man whose professional ability

was beyond dispute, but whose courage and enterprise had often been misunderstood—who attempted great things, and did many great things, and who in some quarters had been spoken of as if, because he tried to go beyond precedent and experience, he was therefore a fanatic or a fool. Mr. Sennett was a man who by what he had done and dared had helped the cause of marine engineering in many ways, and in a manner that had yet to be fully realised. As the Author was present, he would say nothing with regard to him, but would only ask the members to believe that Mr. Durston was too modest to say what he might about his own work, that he had confined himself to a bare statement of fact, and that he was not above learning in any school where there was anything useful to be taught. Dr. White.

Mr. MIERS CORYELL remarked that to appreciate the Belleville boiler an engineer must see it in all the phases of furnace conditions while working at sea, and then after a voyage in preparation for the next one. He knew of no fire-room work so easily performed and so little fatiguing to the stoker, nor where the work could be so readily systematised, he might say disciplined, to advantage; the grates were covered with thin fires always, and the consumption was regulated by the charges being made more or less frequently according to the necessity. The activity of the fires was regulated by the opening more or less of the ash-pan doors, which were the draught regulators. The water-level was maintained by the feed-water regulator which automatically controlled the delivery of the pumps; at the same time none of the usual water-level gauges were omitted and were always in sight, and indicated in the same manner as upon other boilers. The automatic feed-water regulator was not at first well received by engineers; but his experience was that it was absolutely reliable and of great importance as an attachment to a boiler carrying a comparatively small amount of water. Light furnace charges, more or less frequent according to the required expenditure of steam, together with the assured steady alimentation, corresponding with the vaporization, were essential features to produce the best results in any boiler. The speed of the feed-pumps varied with the speed of the main engine, and the steam was never shut off from the pump while there was fire in the furnace, so that the pump not only varied in its strokes but might stop altogether to proceed again when the main engine moved. The purification of the feed-water was perfect, and the sediment was deposited out of reach of the tube-surface. By the action of the Belleville separator the steam was delivered dry at all times, whether the

Mr. Miers
Coryell.

Mr. Miers vessel were rolling or pitching, however violently. To test its control over its steam-making power, that is to say, its safety against undue pressure under conditions that might occur at any time on a voyage, he had tried an experiment—with steam at 250 lbs. per square inch on boilers, the engine working at full speed, a pressure of 220 lbs. per square inch on the piston, and the fires in full activity. The engine had been suddenly stopped, by working the given appliances, and the steam-pressure had risen in five minutes to only 260 lbs. per square inch on the boilers, and in fifteen minutes to 265 lbs., remaining constant at that pressure. Again, under the same conditions as above, except that the engines had been started astern, the boiler-pressure had risen only 5 lbs. in five minutes, remaining constant at that point. As to economy and efficiency he had found them quite equal to those of the best constructed Scotch boiler, which had proved itself in his experience to be free from the necessity of even trifling repairs or adjustments at sea or in port, and from the clogging of the draught passages at sea. Every Belleville boiler was tested to 800 lbs. per square inch upon each detail, and could therefore perfectly safely carry 400 lbs. steam-pressure, and at any pressure salt water alimentation was not injurious. He recognised the wisdom of introducing the Belleville system into the Royal Navy, as it possessed many advantages in durability, in weight and in space occupied, and also in its ability to use any steam-pressure desired.

Mr. Henwood. Mr. E. N. HENWOOD said that the machinery of British war-ships, apart from the deplorable paucity of stokers—in itself a very serious matter—was open to criticism in many and various directions. With regard to the matter of speed, the Author had shown satisfaction at the fact that various war-ships had proved their ability to maintain, without any special effort, a high percentage of their natural-draught power, on time trials of a maximum duration of seventy-three hours. All that could be deduced from that was, that the ships were able to cruise along without disaster, at say, half speed, or about 10 knots an hour under natural draught. He maintained that any system of forced or induced draught would lead to no better results, because it did not dispense with the inherent defects of hand-firing, involving severe and exhausting labour, great waste and inefficiency. The only remedy for the evil was to replace the solid fuel by liquid and to feed the furnaces automatically, thereby maintaining an unvarying pressure of steam for full speed for virtually an unlimited period. Liquid fuel possessed other advantages, such as economy in quantity and space, 1 ton of oil doing the work of 4 tons of coal,

saving of labour, dispensing with stokers, removal of all danger of spontaneous combustion, and avoiding smoke, soot and ashes. Its inherent safety and non-inflammability in bulk, facility of shipment under all conditions, on land or at sea, and its ability to effect perfect combustion were greatly in its favour. The principal objection to the introduction of the system seemed to lay in the fact of England's control of coal supplies. Russia was fitting some of her war-ships of the first class for oil-fuel, and doubtless other nations would do so also; perhaps then the British Authorities would awake to the fact that they, if they wished to equal others in speed and steam endurance, would have to do likewise.

Mr. DAVID JOY said that among the many subjects which had been treated in the Paper, two especially had fallen within the limit of his experience: first, that of water-tube boilers which the late Daniel Adamson called in ridicule "pipulous boilers" as against the Lancashire boiler, and which the Admiralty were taking up so largely. He had had, some years ago, a considerable experience with the Howard boiler, which was found to give good results so long as it was not hard driven, but it had failed when it had been put on board ship. Two ships had been sent to sea fitted with it, and both had been lost. A ship had been built by the Barrow Engineering Company of 600 tons displacement, with engines of 200 I.H.P., and the greatest possible care had been taken in the design of a modification of the Howard boiler. The results of the first trial had been satisfactory, but the second trial had been attended by nothing but accident. The boilers had failed, filling the stokehold with steam to suffocation, and the ship was towed home. A record of all the results, however, showed that the water-tube boiler, maintaining an unfailing all-round circulation, was a very economical boiler, but the circulation was very uncertain and liable to great irregularities, and, if not kept up, a very little variation in the firing of one or other side of the same furnace would drive the water into a condition of effervescence from that side to the other, the evacuated side being immediately subject to be burnt. This had been proved to have been the case in the damaged water-tube boilers of the s.s. "Propontis," one of the earliest of the installation of true water-tube boiler.

With regard to the weight of the rapidly reciprocating parts, in consequence of the speeds being now very largely increased the reduction of the weight of these parts became of great importance. At the Institution of Naval Architects, Papers had been read and illustrated by models, to show how the vibrations were set up in a steamer, by the rapid reciprocations of the unbalanced parts,

Mr. Joy. and further to indicate how they might be prevented or neutralized by balancing or even by adjusting the positions of the weights.¹ These exhibitions, however, had tended rather to point out that the direct way to treat the subject was to reduce the weights, by dispensing with as many of the reciprocating parts as possible, owing to the difficulty of balancing complicated combinations of movement, such as the motion link of an ordinary link gear. Many engineers, retaining the weights, had endeavoured, in the general design of the engine, to obtain the effect of an all-round balance. In this respect, the quadruple-engine had found favour, and the engines to which he had referred, and of which drawings were on the table, were quadruple engines. He had received the assurance from the builders of ships and engines, that the ship was entirely free from vibration at the highest speed. He had treated the valve-gear with the view of diminishing the weight of the reciprocating parts, and had succeeded with a much simplified design of gear in reducing the number of parts to such an extent as to result in a saving of between 60 and 70 per cent. of the weight of reciprocating machinery.²

Mr. Durston. Mr. A. J. DURSTON, in reply, said that Sir Edward Reed, in some flattering remarks on the Paper, had referred to the increase of piston-speed in recent years. For that, with its accompanying lightness of machinery, he thought they were largely indebted to his late friend and predecessor, Mr. Sennett. That gentleman's work had been spoken of by Dr. White in terms with which he fully concurred. Engineers used as large a stroke as the design would allow. As Mr. Thornycroft had observed, engines were certainly lighter with the increased speed of revolutions. The cylinder ratios used in the Navy were not so large as in the mercantile marine, for the naval ship was generally run at a comparatively low power. She performed all long distances at comparatively low powers, and the best results with regard to economy were, he believed, always obtained at between 50 and 70 per cent. of the natural-draught power. On either side of that point economy fell; in one case by not having sufficient expansion, and in the other by having too much, and condensation affecting the result. With regard to the battle-ships "Barfleur" and "Centurion" and cruisers, weight had been added to their boilers and engines, as at the time it was considered, and rightly so, that those ships would have to steam much greater distances than a squadron of

¹ Trans. Inst. Naval Architects, vol. xxxiii., 1892, p. 213.

² *Ibid.*, vol. xxxv., 1894, p. 430.

battle-ships. The distances on the Pacific and China stations were Mr. Durston. much in excess of those run either in the Mediterranean or in the Channel. For future progress, he agreed with Mr. Yarrow—and other engineers were no doubt of the same opinion—that improved design and workmanship, stronger materials, more perfect combustion of fuel, further increased speed of engines and higher pressures of steam must be looked to. With regard to the latter, as far as past experience showed, as pressure of steam had been increased more HP. from a given unit of heating-surface had been gained. As far as the Navy was concerned, the triple expansion-engine would still serve for considerably higher pressures, although the engine might be, and had in many cases been, divided into four cylinders—that was by dividing the low-pressure cylinder into two.

The consumption of fuel had been referred to by Mr. Seaton, and was a very important matter in the consideration of the Admiralty; but most of the trials that were made for periods of less than twenty hours had for some years past been disregarded, because so much variation came in over shorter periods. At the end of the Paper several trials over long periods were referred to. Since the Paper had been written, an account had been received of three ships: in the “Spartan,” a second-class cruiser, 6,777 I.H.P. had been maintained for a run of seventy-two hours, or 96 per cent. of the natural-draught power, producing an I.H.P. from 2.3 square feet of heating-surface. The consumption of fuel had been 1.96 lb. per I.H.P. per hour. The second case was that of the “Resolution,” a battle-ship. There the run had been for forty-eight hours, and the I.H.P. had been 8,085, or 90 per cent. of the natural-draught power. The consumption had been 2.1 lbs. per I.H.P. per hour. In both cases the engine-room crews had been in three watches, and it had been reported from both ships that they could have maintained that power for any time as long as the coal would last. The “Ramillies,” another battle-ship, had also developed for thirty-four hours 8,111 I.H.P., or 90 per cent. of her natural-draught power, on a consumption of 1.97 lb. of coal per I.H.P. per hour. The “Endymion,” in which Mr. Seaton was much interested, had also kept up its character as an economical ship. He might observe that these results were something beyond laboratory experiments.

As to the present position of forced draught in the Navy, of which enquiry had been made by Sir Edward Reed, the present rule was that engines were designed for a certain power at natural draught, which might be called 100; and for a cylin-

Mr. Durston. drical boiler the forced-draught power was made 20 per cent. in excess of that, namely 120. For continuous steaming as long as the coal would last, not less than 60 per cent. of the natural-draught power was to be developed. If less than that was obtained, inquiries were instituted. It had been shown in the Paper that in many instances nearly 100 per cent. of natural-draught power had been obtained over long distances—over such periods that they might say it could have been continued as long as there was any coal in the ship to burn. In action two watches of stokers went below into the engine-rooms and stokeholds. If one watch could produce nearly 100 per cent. of the natural-draught power, it was not an extravagant assumption to make, provided the boilers were clean and the engines properly adjusted, that 20 per cent. in excess of the natural-draught power could be readily produced for a short spurt. He thought that was not overstating the case, he was pretty confident that more would be done, notwithstanding Prof. Biles's bad opinion of the naval engineers and of the peculiar discipline said to obtain in the Navy. He was afraid he could not accept the statement. Whatever that gentleman had said about the naval engineer or about naval discipline applied to himself and to his colleagues.

With regard to the change of type of boilers, the Admiralty had come to the conclusion for some time past that by increasing the pressures in cylindrical and locomotive boilers very much would not be gained, and that it was necessary to turn to some type of boiler that contained less flat and thickly-stayed surfaces. Certain forms of tubulous boilers had shown themselves thus adapted for the purpose of utilizing the higher pressures, and after consideration and investigation of many sets of boilers in actual service, the Belleville boilers had been decided to be put into the "Terrible" and the "Powerful," the largest cruisers. A set had previously been ordered to be placed in the "Sharpshooter." Those boilers were doing very well indeed, and many of the engineer officers (who were not easily persuaded as to the merits of a new thing) who had seen the boilers at work had been much impressed with their ease of management, including ready means for keeping heating-surfaces clean while under way. But in addition to ease of management it was, of course, necessary to have facility for repairs and examinations. That had led, in large ships at all events, to a comparatively large diameter of tube. In tubulous boilers small tubes were thought to be very suitable, and they were certainly extensively applied in torpedo boats and ships of the torpedo flotilla. Three British types of

tubulous boilers were now in use in the Navy: there was the *Mr. Durston*. "Speedy," built by Messrs. Thornycroft; the "Daring," built by the same firm; and the "Hornet" type, by Messrs. Yarrow; and those were being repeated in many other boats. In the "Ferret" and other torpedo-boat destroyers boilers of the Normand type had been fitted, and in a few months it was hoped that several other types of tubulous boilers, British, American, and French, would be passing successfully through their trials. The Admiralty did not care what the nationality was, so long as the boiler was a good one.

With that introduction of the Belleville boiler and the Thornycroft boiler there had also been introduced automatic feed-apparatus, upon which engineers, some few years ago at all events, had looked with some suspicion; but, so far as experience had shown, the apparatus had been found to answer very satisfactorily and efficiently; and if it continued to do so, the reduction of the anxiety on the part of the man in charge of the stokehold, who would then be able to give more time to the firemen, would be appreciated. As to steam-pressures, Mr. Sampson had expressed a hope that they would not be limited. Pressures as high as 210 lbs. per square inch were being used in some engines; but in the case of the Belleville boiler the pressure in the boiler was from 50 to 60 lbs. in excess of that used at the engines. As he had before indicated, the pressures would, no doubt, be still higher in the future. The manner in which the materials stood would have to be followed, and a change of material might be necessary with a change of pressure.

He agreed with Mr. Seaton that the limit of power from any boiler, whether tubulous or otherwise, was the quantity of heat transmitted through a unit of heating-surface with safety. The Table towards the end of the Paper had been referred to by Mr. Thornycroft, who had desired some corrections to be made. The weights there given for boilers were for cold water; in the Tables of the Appendix, however, in every case the weight was for hot water. The powers of the "Daring" and the "Ferret" required a slight alteration. They had been inserted before the official record was received. The figures 4,300 for the "Daring" should be 4,400, and for the "Ferret" 4,500 should be 4,774. It would be observed that the figures in the last column were not very materially altered, and they gave a very fair measure of the efficiency of the respective types. The excessive heating-surface of the "Speedy" in the same Table had been complained of by Mr. Thornycroft, but he had used that same excessive heating-surface

Mr. Durston. in producing a certain figure of merit, in which it had been used as a divisor. As to priming, he could only say that in the "Speedy" two forced-draught trials were discontinued on account of it. It was the leakage of sea-water through the condenser-tubes that had caused the boilers to prime so violently that the trials had been discontinued. That opinion had been supported by Mr. Thornycroft when he spoke of a reservoir that was fitted in the "Geyser" with some other apparatus especially provided against priming. He understood that there was a reason for the existence of that reservoir. Putting that on one side, however, he was glad to say that the "Speedy" was doing very well with regard to economy. With the introduction of a higher pressure of steam, and with the tubulous boiler, very economical results had been obtained from the "Speedy's" machinery. He concurred in preferring steel tubes in water-tube boilers, as they were strong enough to resist the internal pressure when considerably over-heated. On that ground they were preferred in cylindrical and locomotive boilers. They were of more uniform material than Staffordshire iron, which had been used before, and they would stand the rolling in the tube-plates better, which was an important point in their favour. They also resisted leakage equally well. Another point was that the boiler was all of one material.

As to the systems of accelerated draught, as in the case of sails, the days of trusting to funnel-draught had passed. The fires and men must each have a good supply of air under all conditions of climate and atmosphere. So far as his experience had shown, the most compact system was that known as forced draught, which embodied a closed stoke-hole with fans supplying the air to it and the fires. The chief objection to that system was the closed stoke-hole, the air-tight casings, the double doors, and the air-locks accompanying them for ingress and egress. Next in order came the induced draught with fans in the funnel, and, in addition, fans for ventilating the stoke-hole. Having open stoke-holes, air-locks, doors and screens could be dispensed with, and, as had been stated in the Paper, there was a greater economy of fuel with that system. Why, he did not know, nor, he believed, was it known to those who carried out the experiments. There was more uptake work, of course, with induced draught. Besides those two systems, there were those known as the "Howden" and the "Ellis-Eaves." Those systems involved, in addition to the other two, the provision of air-heating apparatus, in the shape of a number of tubes. All these various appliances had been care-

fully considered, and the conclusion arrived at was that no advantage could be gained in their adoption for war-ship machinery, as neither system, as far as could be ascertained, had yet an installation in existence which in actual work could give so much I.H.P. per ton as that of the forced draught. Another point was the doubtful advantages of those two systems. The air-heating system would only come in at high powers, and not at the low powers used on ordinary service. As Dr. White and Mr. Seaton had remarked, the Admiralty did not make changes without purpose. He and his colleagues had had the hearty co-operation and criticism of the machinery contractors as well as of the naval architects; and their brother engineers and officers afloat, both by their work at sea and by their criticism, served them at the same time. They invited criticism, but it must be expected that there would be some piquancy in it. In acknowledging the manner in which his Paper had been received, he did so on behalf of his colleagues as well as of himself, for without their constant goodwill and helping energy, their chief could do but little.

Sir ROBERT RAWLINSON, President, was sure that the members present had been pleased to listen to the interesting discussion which had taken place on the Author's most valuable Paper. He could assure the meeting that there were many people outside who would have been glad to have had the advantage of the information given within these walls. An American gentleman had said to him, "Oh, yes, it is very generous of you to give us all this information; but I beg to tell you that we know it. There is nothing new. You tell us what you have done, but you do not tell us what you are doing now." Sir Robert Rawlinson individually was glad that there was that reservation. People would get to know what was being done in due time. The question of steam-power as applied to ships of war was one of the most important questions of the day. Ships of war were built, and he assumed that builders constructed them for use. If he could have his way they should be burnt, but then there would have to be by consent a general burning all over the world. The millennium, however, had not yet arrived. He could only say that it was most generous on the part of the Admiralty to permit its officers to bring forward and to illustrate the work they were doing with the nation's money—that information being thus made available for merchant shipbuilders, as also for all workers in iron and steel; and it was an enormous advantage to discuss before the Institution the properties of the material used, and the way in which it was used. Machinery now went upon the principle of

Mr. Durston.

Sir Robert Rawlinson.

Sir Robert Rawlinson. quick revolution to attain a high speed. All machines that were built to move rapidly were built to wear out rapidly, and would have, therefore, to be renewed from time to time. No doubt improvements would be introduced, and nations who engaged in that kind of work must take advantage of these, in order to keep their place in the world. He begged to thank all those who had taken part in the discussion, and who had added to the information given by the Author of the Paper.

Correspondence.

Mr. Isherwood. Mr. B. F. ISHERWOOD, Chief Engineer, United States Navy, thought the Paper intimated to the engineer that, under the present conditions of practice, he was at the limit of his resources in the production of power relatively to weight of materials used. A halt was thus called pending a new departure, and the enquiry was: Could the weight and space of the present machinery be further materially lessened by any practicable modification, or by any changes?

As the Paper did not deal with principles, but was confined to pure statement of facts, all that could be said concerning it was the expression of the highest appreciation of its practical value, and the hope that it might be supplemented by other similar Papers furnishing the exact dimensions of the vessels and machinery, including waste spaces at cylinder-ends, diameter of piston-rods, and drawings of the propelling-screws. Also, that the Author would describe, in as much detail as possible, the trial performances of these vessels, supplying average indicator-diagrams. His official position enabled him to obtain the precise figures, and he could do his profession, his Government, and the public, no greater service than to give this useful information to the world.

Returning to the Paper under discussion, Mr. Isherwood would endeavour, as germane to the question, to show how, in his opinion, the ratio of weight to power in the case of marine machinery could be still further lessened without too radical a departure from current practice, and without going beyond the methods and means at present in vogue. Multiple-cylinder steam-engines, including in that term the compound, the triple-expansion, the quadruple-expansion, &c., had superseded single-cylinder steam-engines, because they were practically necessary for the use of steam of continually-increasing pressure, while such higher pressure steam