Discussion.

The President. The PRESIDENT, in moving a vote of thanks to the Author, remarked that the Paper was the first that had been read before the Institution on the subject of the use of internal-combustion engines for marine purposes, but he felt sure it would not be the last; the younger members of the Institution, at any rate, were likely to hear a great deal on the subject later on. The Paper was largely confined to dealing with one particular aspect of the internal-combustion engine—the question of variable speed and balancing; but the discussion could take place upon any subject connected with such engines, even though many of the points had only been very briefly touched upon by the Author.

Mr. Dugald Clerk.

Mr. DUGALD CLERK observed that the interesting subject of the Paper admitted of a great variety of opinions, and he thought the Author would not be surprised to learn that although he agreed with him on some points he differed from him upon others. It was very interesting to Mr. Clerk, as an engineer accustomed to design gas-engines, to have the ideas of a steam-engineer upon a problem that had occupied his mind and work for about 30 years. He need hardly say that the question of the application of internal-combustion engines to the propulsion of ships was one which had occupied his attention; and at the present moment he was designing engines which he hoped would fulfil that purpose. He agreed with the Author in, for example, the list of requisites for a marine gas-engine of large power; there was no doubt that it was necessary to get rid of everything that might be described as “motor-car tricks.” In the motor-car and the motor-boat the power was so small that it was possible to introduce clutches and reversing spur-gearing, but anything of that kind was entirely out of place, and would be exceedingly dangerous, in a large gas-engine for marine purposes. He also agreed with the Author that the idea of separating the pump and the motor-cylinder was a very fascinating one, and if it were possible to suppress the whole negative work of the gas-engine the problem of driving a ship would be nearer solution. He agreed with him more particularly because the cycle which the Author proposed was one which had attracted his own attention very early. In 1878 he built a gas-engine which gave the diagram shown in *Fig. 9*; the engine was supplied with a compressing-pump, taking in gas and air, and compressing the gas and air into a reservoir. The

mixture was taken into the engine-cylinder during the first portion of the motor stroke, just as was indicated in *Fig. 9*; then the ignition took place when the cut-off closed, and there was a somewhat rapid rise—in some cases too rapid; and then an expansion-curve was obtained as shown in *Fig. 9*. That engine was exhibited at the Kilburn Show of the Royal Agricultural Society, in 1879, and he believed it was the first compression-engine giving an impulse every revolution that was ever built. Unfortunately, although that type of engine was a very fascinating one, and had many advantages, it presented certain difficulties, some, but not all, of which the Author appeared to have realized. It was possible to get with it very high economy and a good operating engine; but its very pronounced disadvantages had induced Mr. Clerk to design a new type, a two-cycle engine—he had mostly worked on two-cycle types—and that engine appeared for the first time in Paris in 1881. It embodied the well-known Clerk cycle which was now used on a large scale in the large Körting and Oechelhäuser engines built in Germany and Great Britain. That cycle, however, also had disadvantages—all gas-engines had disadvantages of one kind or another—and in 1886 he again attempted to build engines giving a diagram such as *Fig. 9*, and succeeded fairly well. He built a number of very economical engines, but they were found to be too delicate for ordinary small-engine work: the adjustments were too sensitive. In the early engine of that type one of the chief difficulties was the necessity of compressing the gas and air to the full pressure, of admitting that gas and air into the motor-cylinder at that compression, and of then igniting the mixture. The interval allowable between the ignition of the mixture and the closing of an admission-valve was very small, because at that time the piston was beginning to move at its maximum rate; and the consequence was that, if the ignition was not brought on sharply, whenever the admission-valve shut the ignition would occur very far on in the stroke, and the effect would be at once to reduce the expansion and the power. In order to avoid that, the tendency was to bring the ignition on rather too soon, and if the speed of the engine slackened a little, occasionally, but not very often, the flame was too quick and passed back into the reservoir, and the whole of the reservoir was put under the maximum explosion-pressure; that was to say, if the working-pressure was about 200 lbs. per square inch the reservoir had to withstand that pressure. But there was a worse difficulty than that. It was possible to make the reservoir withstand 200 lbs. per square inch, but before the engine could begin working again on its

Mr. Dugald
Clerk.

Mr. Dugald
Clerk.

usual cycle, enough gas and air had to be pumped into the reservoir to clear out the products of combustion formed therein. The consequence was that in his next attempt to make an engine operating upon the cycle which the Author had described, he made up his mind to omit the reservoir, because before the speed picked up again, if there was any load on the engine, the engine often stopped. In the engine of 1886 and 1887, which he had had the honour of describing¹ to the Institution in 1896, he arranged a pump at the side of the motor-cylinder with the minimum of clearance between the pump and the motor, the pump being so arranged, in regard to its crank-angle, that when the motor-piston began to move forward communication was made through a short port of small capacity, with the result that the pump forced the charge into the motor-cylinder just as it was compressed, without any intermediate reservoir. That method had been applied also by Mr. Atkinson, now of Messrs. Crossley Bros. and then of the British Gas-Engine Company, and Mr. Clerk thought that Mr. Atkinson and himself must have built engines of that type numbering in the aggregate about forty or fifty—engines that were actually in use, giving fairly good results, but also giving trouble from the delicacy of the ignition-adjustment. It was true that the Author's engine was meant to work at a lower speed. The Author proposed about 90 or 100 revolutions per minute, and at that speed he would have less trouble in getting the ignition properly timed, but he would have a diagram somewhat different from the one he had shown. The Author's diagram (*Fig. 7*) had a level admission and then a straight run up, but the fact that the valve took time to close and time to open, would round off the diagram, and when the valve cut off it would cut off some time before ignition occurred, and immediately the valve cut off the pressure began to drop. [The speaker drew an illustrative diagram on the blackboard.] Diagrams of that character would be found in Mr. Clerk's Paper read before the Institution in 1896. Then, although the ignition, whether flame or electric, might be brought on very quickly, the flame took considerable time to travel through the whole cylinder and yield the maximum pressure, and consequently even at the best a diagram was obtained with a sloping rising line, as in *Fig. 40* of his 1896 Paper.² If the ignition happened to fail a little longer than usual, a diagram might be obtained like *Fig. 41* in the same Paper. If, as was usual in large engines nowadays, the gas had

¹ D. Clerk, "Recent Developments in Gas-Engines." Minutes of Proceedings Inst. C.E., vol. cxxiv, p. 96.

² *Ibid.*, p. 125.

been admitted at one-sixth or one-seventh, and then cut off and fired, it was probable that before there was any real effective maximum pressure something like one-quarter of the total stroke had been reached. That reduced greatly the mean pressure possible and also the economies. He would be very proud if the Author succeeded in running the engine, because it was one that had interested him for many years, the only point of difference being that the Author drove the gas- and air-pumps separately. It was true that by supplying the gas and air separately to the cylinder the ignition into the reservoir would be avoided, but there were certain difficulties even there. That method had been tried by Mr. Atkinson and himself independently. On the whole, in the present stage of knowledge, until the Author had built an engine of that cycle and shown that he had overcome all the difficulties that puzzled the rest of his fellow-workers, Mr. Clerk preferred the well-known Otto cycle, and next to that he preferred the Clerk cycle, although on the whole he thought the Otto cycle was the safest. The Clerk cycle with a clearance-space at the end, exhaust ports over which the piston ran, and the displacing arrangement, gave all the advantages that the Author called for, without the loss of pressure to which he referred. With the Otto cycle, however, although there was, no doubt, the disadvantage of the one explosion for two revolutions, yet there was an advantage in certainty of charging, in the certainty that exactly the expansion arranged for was obtained, and in ease of operating the valves. The valves in the Otto cycle could be operated with much ease because there was plenty of time to raise them and drop them at the end of the stroke. The Clerk cycle had the slight disadvantage that the valve was operated rather quickly, because little time was allowed in exhausting on the out exhaust ports. Consequently he would place in order, first the Otto cycle, with perhaps a six-cylinder engine if single-acting, or a three-cylinder engine if double-acting, and secondly, the well-known Clerk cycle; although he would be very glad to see an experimental engine built of the type described by the Author. He had no doubt it could be made economical, but there would be great difficulty in preventing back ignition and consequent reduction of the economy. He hoped the Author would not feel that in criticizing the Paper Mr. Clerk was in any way adverse to his ideas.

Mr. Dugald Clerk.

Professor F. W. BURSTALL felt disposed to wonder sometimes whether steam-engineers quite realized all the minute difficulties that had to be dealt with in gas-engines of any dimensions. He could speak somewhat feelingly on that subject, as he had

Prof. Burstall.

Prof. Burstell, lived for about $2\frac{1}{2}$ years in daily touch with a high-compression gas-engine and he knew what the difficulties really were. In the light of his own experience he was very glad that he had not the job of running an experimental gas-engine built on the lines the Author had indicated. Mr. Clerk had given his experience of the early two-stroke-cycle engines, but had not alluded to the fact that in those days, with coal-gas, they worked at very low compression, that was to say, at probably 50 to 60 lbs. per square inch. When power-gas was used, in order to get economical working it was necessary to go to much higher pressures. With producer-gas of the Dowson or Mond type it was necessary to run at 100 to 110 lbs. per square inch compression, and on blast-furnace gas even higher. Increased compression introduced great difficulties, which were entirely absent from the small gas-engines hitherto used. He would allude to the action that took place later on, and would merely state there that, while those cycles might answer perfectly well on 55 lbs. per square inch compression, they were at least risky with high compressions. The first point he desired to comment upon was the fact that the Author did not say anything about the difficulty of building large vertical gas-engines. It was assumed that because it was possible to build a big horizontal engine it was also possible to build a big vertical one. In the course of the last 7 or 8 years he had probably seen forty or fifty vertical gas-engines, ranging from 200 to 1,500 HP., and not one of them was what he would call a real commercial success, suitable for the onerous work of driving a ship at sea. Why the big vertical engine was not a success he could not say, but he knew there were problems to be solved in a vertical gas-engine that did not exist in the horizontal gas-engine. In the second place, the Author alluded to the need of reversibility, but gave no clue to the solution of this very difficult problem. The only way of reversing a four-stroke-cycle engine was by having some method of disengaging the valves; the whole cam-shaft must be disengaged, slipped round through half a revolution, and re-engaged again, while in the meantime the compressed air must be put on to stop the engine and to start in the opposite direction. The whole operation required very complicated mechanism to effect it. Reduction of speed was, of course, a simple matter. Anyone who had driven a six-cylinder motor-car knew that it was possible to drive through very wide ranges of speed without a change of gear; all that was required was to alter the lead of the ignition-spark and to cut down the charge. He did not wish to say that the same thing could be done in the present instance, but would just say what he had done on the gas-engine at the Birmingham University. There

were two methods of governing: quantity governing, that was Prof. Burstall. reduction of the total quantity of mixture, and quality governing, by reduction of the gas alone. As to quantity governing, it was perfectly correct to say that it was not possible to go below a certain point in a non-scavenging engine, but with a scavenging engine it was possible to go very low. The objection to quantity governing in land engines was of course that it made the mechanical efficiency very poor at light load, owing to the back pressure of the piston; and moreover it caused the lubricating oil to be sucked into the motor-cylinder and gave rise to serious incrustation. However, for marine purposes, there was no great objection, because for the most part the engine was running on full load constantly and then the mixture governing was quite as good as the other. In quality governing it was easy to reduce the mean pressure as low as was desired without cutting any charges out. He had worked at from 120 lbs. per square inch mean pressure down to 15 lbs. without cutting out a single charge, by the simple operation of altering the time of the ignition-spark, which of course had to be advanced as the load fell. That had been done with a compression of about 155 lbs. per square inch on Mond producer-gas; but there was no difficulty whatever in running an engine slowly, provided there were enough cylinders to equalize the turning-moment. With regard to the double action, double-acting cylinders, at any rate in the hands of English firms, had not been an unqualified success. The Germans, it was true, had succeeded, but it must be remembered that the German engine was relatively a larger engine than the English for the same power; moreover, most continental engines were built for blast-furnace gas, in which the problem was very much simpler. In view of all the difficulties of building a reliable marine motor, he suggested that it would be wise in the first instance to stick to single acting. He went a little farther than Mr. Clerk, and proposed a six-crank engine with twelve cylinders, the cylinders being arranged tandem one above the other. That gave a very convenient arrangement, as regarded both turning-moment and ease of throwing the compressed air into the top line of cylinders for both starting and reversing. The idea of separate compressor-pumps was by no means novel; he had known about it for nearly as many years as Mr. Clerk, and, like most people, he had been greatly fascinated by the more or less perfect analogy with the steam-engine: it looked so simple. He quite agreed with the diagram Mr. Clerk had drawn on the blackboard, but thought that probably it would be even worse. He would expect to find what he called a "flaming" diagram.

Prof. Burstall. He had found that the time of passing of the ignition-spark was always before the dead centre, even when there were no signs whatever that ignition had taken place before the dead centre; that was to say, the time which the mixture took to inflame was quite appreciable, and the speed of flame-propagation was evidently about the same as the piston-speed of the engine, which in his own case was 700 feet per minute. But even if a diagram such as *Fig. 9* were obtained, he did not think the results would be economical, viewed in the light of common practice. Economy was a relative term. What was economical 10 or 15 years ago was very poor now, and when he spoke of an economical engine he meant one using about 0.7 lb. of common coal per indicated horse-power-hour, or, put in another way, about 48 cubic feet of Dowson or Mond gas. In order to utilize that, it was necessary to have a compression of about 120 lbs. per square inch. If separate compression-cylinders were used, the temperature in the air-compressing cylinders would be something like 660° F., and that was too high to run without water-cooling the compression-cylinders. He might, perhaps, be met with the statement that the explosion-cylinders had to be cooled, and therefore it did not matter, but he thought he could show that it did matter. In the next place, the motor-cylinder was being subjected to a continuous series of explosions without any cooling at all. In the four-stroke cycle some cold air was drawn in, and the inner surfaces were cooled. When he said that the liner of such a cylinder as was mentioned in the Paper was $2\frac{1}{4}$ inches thick, it would be seen that the inner surface of the explosion-cylinder would become very much heated in spite of the water on the other side; in fact, it would become heated to such a degree that he would expect premature ignition of a violent character. In order to justify the point he had just made with regard to the jacketing of the pump-cylinder, he would give what he considered to be the action in the four-stroke-cycle engine, deduced from a large number of engine-trials. In place of starting with compression, he started with explosion. During explosion a large quantity of heat passed from the charge into the wall, and this heat continued to pass into the wall until the exhaust took place, and even possibly after. Thus the inner layer of the wall was heated to a temperature of perhaps 600° to 700° F. During the next stroke the exhaust was passing out, and the heat was sinking deeper into the wall until the suction-period was reached, when cold air and cold gas were drawn into the engine-cylinder. They began to take heat from the wall, and continued to do so, not only throughout suction, but throughout the greater portion of the compression. The wall, therefore, acted as a regenerator: it stored up heat on explosion, and

restored some of it on compression, and he ventured to think that that was the reason why the four-stroke cycle was so economical. He had been unable to get accurate figures of the two-stroke-cycle engine of the present day, but certainly there was 6 to 7 per cent. difference in thermal efficiency between the two, and that he thought was very largely due to the regenerative action of the motor and pump being in one. It might interest the younger members to hear that all the information ever brought to light in connection with gas-engine work was contained in the patent-specification of Beau de Rochas dated 1857. He was unaware that anybody had ever found out anything on the subject of the economical utilization of gas that was not contained in that very remarkable work, all the more remarkable as being the conception of a man who could not have known anything of gas-engine work, inasmuch as no gas-engine of any kind had ever been built. He looked upon that patent-specification as almost an inspiration.

Engineer-Lieut. W. P. SILLINCE, R.N., had listened with great pleasure to the proposals of the Author, who had certainly dealt fully with the problem of adapting the internal-combustion engine to marine purposes. But he rather thought that gas-engines had gone on a little too fast. Nearly all the large gas-engines referred to by the Author employed either blast-furnace or coke-oven gas, and there was no difficulty in the matter of producers, because they used products which would otherwise be wasted. But, unfortunately, for the purposes of a ship it was necessary to consider the problem of making a gas-generator before making a gas-engine to use the gas generated. The Paper did not deal with the subject of the gas-producer, and he was afraid that the gas-producers had been rather neglected, particularly in England. Pressure gas-producers were under construction using bituminous coal, and of such size as to be capable each of supplying gas-engines of 3,000 HP.; but the gas-cleaning plant in connection with such producers would be much too bulky and heavy for use afloat; and, in addition, there were the risks of gas under pressure. Producers on board ship would have to be worked in confined spaces, and under these conditions gas-producers generating gas under a pressure greater than that of the atmosphere would be highly dangerous. The gaseous products obtained in the chemical reactions of these producers were nearly odourless and highly poisonous: he had once had a mouthful of such gas, and he did not wish for another. Given a battery of such producers in the confined stoke-hold of a ship, if there were even a small leak, the gas would accumulate, and,

Engineer-Lieut. Sillince.

Engineer-
Lieut. Sillince.

being unable to escape owing to the difficulties of ventilating such confined spaces, trouble might ensue. It therefore appeared to him that it was necessary to see a further development of the suction gas-producer of comparatively large power. The difficulties were considerable, particularly when there was not one producer only, but a number in parallel, like a battery of boilers. Producers designed to be accommodated on board ship nowadays used anthracite or coke; if they could use hard steam coal, such as Welsh coal, it would be a great advance. To be able to use bituminous coal was perhaps the ideal state of affairs, but, as an intermediate step, a suction producer which could use such coal as an ordinary Welsh steam coal would be a great help in forwarding the solution of the problem of the propulsion of large vessels by means of gas-engines. He was afraid he was not in a position to criticize the experimental difficulties of such engines. He knew that gas-engines had peculiar difficulties of their own which were often hard to surmount; at the same time, there were certain points in the Author's proposals which appeared to him to be worth mature consideration. First of all, there was the separation of the compressor. Unlike most two-cycle engines in which the charge was compressed in the working-cylinder, and in which the period of exhaust was very short indeed, the Author's proposed engine would devote the whole of one stroke to the exhaust; and this would tend, in comparison with ordinary two-stroke-cycle engines, to dissipate those accumulations of heat which caused trouble in the working of the piston in the cylinder, the heating of valves, and so on, eventually ending in overheating or premature ignition. In the Author's engine there was one stroke devoted to exhaust, as there was in the four-stroke cycle, and it was to be hoped that an experimental engine would be built on some such lines. Economy under certain circumstances might be subsidiary to other considerations. It was unfortunate to see such a large amount of negative work in connection with a separate compression, although he was not sure that it need be much larger than in the ordinary cycle. For example, he noticed that if it were required to instal engines of 3,000 I.H.P. on the main shaft, it was necessary to carry compressors, of roughly, 1,500 HP., together with the engine to drive the latter. Where weight was a consideration, this arrangement might be prohibitive, and whoever had to pay the bill might rather object to paying for 6,000 HP. of an expensive type of machinery when only getting a net 3,000 HP. out of it. As compared with the gas-engine, the oil-engine offered many advantages for marine purposes, principally due to the entire elimination of the gas-producing and gas-

cleaning plant, including the apparatus necessary for the generation of steam for the gas-plant. If oil-engines were to be utilized to any considerable extent for marine purposes they must be capable, except in very special cases, of using a cheap fuel, and one which was safe under all conditions of temperature likely to be found in machinery compartments, especially as it would, in all probability, be stowed either within, abreast of, or beneath such compartments. The question of the adequate supply of considerable quantities of such suitable fuel, if its use became general, would be a matter for serious consideration. It should be borne in mind, however, that an oil-engine which could deal successfully with residual oils, fuel oils, or crude oils of high flash-point and high viscosity, would work generally with much better results on refined oils of a lower flash-point if required; although the converse of that by no means applied. He agreed with the conditions laid down by the Author for a successful marine internal-combustion engine; but if internal-combustion engines were to be adapted for naval purposes there were certain additional conditions which should be complied with as far as practicable. First, the engine should be compact and as light as was consistent with good working and maintained reliability; secondly, the engine should be well balanced in order to avoid vibration-troubles; and thirdly, the design should permit of the machinery being placed behind armour protection, preferably entirely below the water-line. Of course in special vessels the last condition would have to be waived. The first condition, the limitation of weight and space, suggested the adoption of high piston-speeds and high speeds of rotation, whilst the second, the balancing, necessitated multi-cylinder engines unless balance-weights were fitted—and they were best omitted wherever possible. With an internal-combustion engine of given power and type it would generally be found that there was a certain piston-speed which it was undesirable to exceed. The speed of rotation at which the engine developed its power depended largely on the weight allowed, since the weight per horse-power decreased as the speed of rotation increased. When the speed of rotation and the piston-speed were decided on, a certain maximum stroke followed, associated with which there was generally a certain cylinder-diameter which it was desirable not to exceed. It therefore followed that, for an engine of given type, piston-speed, and speed of rotation, there existed a certain maximum stroke-volume per cylinder, and consequently a certain maximum horse-power per cylinder; from which it also followed that if the weight available for machinery was very limited, as in small craft of high power, the

Engineer-
Lieut. Sillince.

Engineer-
Lieut. Sillince.

solution seemed to lie in high speeds of rotation, and consequently a considerable number of cylinders; whilst for those cases in which the weight was not so limited, a longer stroke, a lower speed of rotation, and a smaller number of cylinders, would be permissible. It was probable that double-acting tandem engines, except possibly in large vessels for the merchant service, would be found prohibitive on the score of head-room required and the consequent inadequate protection, apart from the difficulty of arranging the valves and their operating-gear. The effect of the inertia of the reciprocating parts at high speeds of rotation, especially if pistons and piston-rods were water-cooled, would be considerable, but in a double-acting cylinder working on a two-stroke cycle, or in a double-acting tandem engine operating on either a two- or a four-stroke cycle, the compression could be made use of to reduce inertia-effects. The most promising solution of the vibration difficulty appeared to lie in a six-cylinder, six-crank arrangement, or multiples thereof, particularly as that arrangement, in addition to being perfectly balanced, gave a fairly equable turning-moment with an entire absence of dead points in starting or reversing. The two-stroke-cycle engine offered many tempting advantages for marine purposes, especially with regard to the simplicity of the valve-gear and of the reversing mechanism, and the economy of space. In large sizes, however, the difficulties connected with the dissipation of heat were serious, though there was every prospect of those difficulties being overcome in the near future. Oil-engines using heavy oil and working on the Otto cycle had been made reliably reversible in sizes up to about 80 B.H.P. In the case he was citing, the engine, although not outside those limits to which a reversing propeller or a reversing gear would apply, had been made with the object of demonstrating the possibility of making a reliable reversing oil-engine, and the object of the experiment had been achieved. There was no reason to suppose that 80 B.H.P. was by any means a limit. At present the power per cylinder in the oil-engine was small as compared with that of large gas-engines. The largest oil-engine he was aware of worked on the Otto cycle, single-acting, and developed between 180 and 200 H.P. per cylinder. The prospects of the internal-combustion engine for marine purposes were distinctly promising, but especially so in smaller sizes and up to 1,000 H.P. per shaft. A number of internal-combustion engines were either fitted on board certain ships of the Navy or nearing completion at the makers' works, for the purpose of generating electricity, whereby it was hoped the work of the boilers, especially in harbour, would be relieved to a considerable extent; and also others were used for the propulsion of service boats.

Dr. H. S. HELE-SHAW observed that the major portion of the Dr. Hele-Shaw. Paper was devoted to a discussion of the variation possible in the well-known four-cycle gas-engine, especially in its application to marine purposes. No one would deny that that was a very interesting subject, but considering the wide range indicated by the title of the Paper, he ventured to think that some of the points which were either ignored or passed over cursorily were as important as, if not more important than, those to which the Author had devoted special attention. If instead of "large engine" the Author had used the words "large power," there was an altogether different variety of engines from those the Author had touched upon which might well be considered, and which, if they became large enough for application to large ships, would revolutionize the engine-room even more than the application of the turbine had done. He had in mind a reversing engine of 360 HP.; he took that particular engine merely because it was reversing, not because there were not many other engines now working of even higher power. He referred to the Antoinette engine, which had proved to be very practicable, and had given no trouble whatever, although it had twenty-four cylinders. A smaller engine built on the same plan as the Antoinette engine was before the meeting. Although it developed 35 HP. it could be lifted with one hand. It was not quite complete, but it lacked only the accumulators, and if magneto-ignition were used the weight of the accumulators could be dispensed with. That engine weighed 88 lbs.

Sir WILLIAM WHITE, K.C.B., Past-President, inquired the number Sir William White. of revolutions.

Dr. HELE-SHAW replied that the speed was high—1,800 revolutions Dr. Hele-Shaw. per minute. The Antoinette engine of 360 HP. weighed 1,500 lbs., plus 160 lbs. for the accessories, which worked out at $4\frac{1}{2}$ lbs. per horsepower. It had important advantages: there was no fly-wheel, and because there were so many cylinders, the engine was reversible. The reversing action was quite easy. The cam which regulated the valves was easily operated by a little machine and a mere touch was sufficient to reverse. The engine had of course to be allowed to stop before the operation for reversing was performed, but a well-made cylinder retained its charge ready to fire when the sparks were put on again.

Sir WILLIAM WHITE asked what was the interval of time.

Sir William White.

Dr. HELE-SHAW said the reversal was almost instantaneous. The Dr. Hele-Shaw. spark was cut off, leaving the compression on, and the engine stopped instantly, then it was reversed, and it was on again before it was possible to see what had happened. The engine he exhibited

Dr. Hele-Shaw. had been made for a flying-machine. Referring to the Beardmore engine (p. 114), it would be found that a 500-HP. producer-gas engine for marine purposes weighed 45 tons for the engine and 20 tons for the producer, a total weight of 65 tons for the plant, the weight per horse-power being 280 lbs., or about sixty times as much as in the Antoinette engine. But the latter engine possessed a further advantage. The Author very properly made a strong point of the fact that it was difficult to reduce the power in gas-engines in the same way as in the steam-engine, by cutting off. With twenty-four cylinders, or any large number of cylinders, it was quite easy to have an arrangement for raising the exhaust-valves of any required number of cylinders, thereby putting them out of action at once and reducing the power in any desired degree. But, on the other hand, there were serious difficulties. Using petrol fuel it cost ten to twenty times as much to run the Antoinette engine as to run an ordinary steam-engine; but there were many internal-combustion engines working on petroleum, the price of which was less than half that of petrol and might be further reduced if the fuel were purchased in bulk. Although in England the cost would undoubtedly be prohibitive in comparison with coal, it was not so in many other places. Liquid fuel was actually cheaper, for instance, on the Pacific coast, in Russia, and so on, and it was obviously possible to build ships for many other places besides Great Britain. Still, the fuel question was a serious one. Engines had been working for years with petroleum, and as long as they had constant work they worked well. It was much more difficult in a motor-car, because the conditions were so variable; the temperature-changes, the variations of speed, and the objectionable smell, which under proper conditions at sea was not noticed, were very marked in connection with the motor-car. There were also other objections to such small high-power engines. First there was the multiplication of parts. In actual working, the engine, as far as certainty of action was concerned, left nothing to be desired. Formerly it had been very different, but to-day an engine would run in long-distance trials 5,000 miles without stopping, which proved the possibility of getting certainty of action in spite of the multiplicity of cylinders. The initial cost of the first engine was high, but it was well known that the cost rapidly diminished as an engine developed. Although he had shown the reversing engine, he did not hold that a reversing engine was necessary, and there he joined issue with the Author. The Admiralty were even harder to deal with than Lloyd's in the matter of getting things passed, yet they had passed in the "Dreadnought"

the principle of reversing gears—gears which reversed with a clutch Dr. Hele-Shaw. —as being quite satisfactory in their action and quite safe. The modern high-tensile nickel-chrome steel allowed wheels to be made which contravened all text-book rules. In motor-car practice he had seen wheels, which had worked at many times the stress allowable in theory, apparently as good as new after running 30,000 miles. Therefore he did not see why engines of that type should not be coupled up in batteries to propel ships. Turbines had led the way in the matter of multiplication of shafts. He saw no reason why such an engine should not develop much larger powers than those which the Author had mentioned as at present in use in internal-combustion engines. If there was any doubt in applying the Author's reasoning from a small scale to a large scale, he would ask the members to remember what was said when the "Turbinia" made her marvellous run at Spithead between two lines of battleships: "A small boat like that is all very well, but it can never be applied on a large scale." He believed that was the moral to be applied to the little engine he had shown that evening. In conclusion he wished to express his thanks to the Adams Manufacturing Company for the loan of the engine.

Mr. H. C. ANSTEY remarked that no doubt great advances had Mr. Anstey. been made in regard to the possibility of gearing for reversing, but there was one consideration which limited it. Although by the aid of gearing the necessity for running the engine in either direction could be obviated, yet it did necessitate coupling and uncoupling the engine from the propeller-shaft, and that meant some form of clutch. In order to transmit a reasonable amount of power per revolution it would be necessary to have a fairly large diameter, and as the centre-line of the shaft must be somewhere below the water-line, it was impossible to get more than a certain diameter of friction-clutch, and that would limit the amount of power that could be transmitted per revolution, although it might be admitted that things were done now by clutches and gearing which were not dreamt of some years ago. The Author laid down as an axiom that the engine must be reversible, and Mr. Anstey was able that evening to give, by permission of the Admiralty, a description of the reversible engine which had been alluded to by Lieut. Sillince. The engine was a four-cylinder vertical engine of the enclosed type, developing 80 B.H.P. The four cranks were arranged as two pairs, each one of a pair being opposite the other, and the plane of one pair being at right angles to the plane of the other pair. The cranks as seen in end view were thus 90° apart. That arrangement, while not giving the best turning-moment, had been adopted for facilitating

Mr. Anstey, starting and reversing. The engine in normal running, either ahead or astern, worked on the usual four-stroke cycle, each cylinder having the same cycle of working as the ordinary Hornsby engine as applied to other purposes. There were separate sets of cams for both ahead and astern, the cam-shafts being capable of motion end-ways to bring either set into action. In addition, there were the cams necessary for actuating the air starting-valves and fuel oil-pumps. Starting in either direction was effected by compressed air, which operated on three cylinders only, giving each cylinder a working stroke every revolution. The remaining cylinder was always on the normal working cycle. The cycle of operations was then the following. Supposing the engine was stationary when an order was received to go ahead, the first motion would be to put the starting-lever into position for starting ahead. Compressed air was then admitted in turn to cylinders 2, 3 and 4, and the shaft began to move in the required direction. The crank of cylinder No. 1 was carried round, and at the end of its first compression-stroke after starting, it received an impulse due to its own charge of air and oil. The next motion was to put the starting-handle into the position for working ahead, the effect of which was to change cylinders Nos. 2, 3 and 4 from their two-stroke cycle, using compressed air, to their ordinary working four-stroke cycle. No. 1 cylinder remained at work unchanged by that operation and kept the engines running, while cylinders Nos. 2, 3 and 4 in turn picked up their ignition at the end of their first compression-stroke after the cams had been put into their working position. An exactly similar series of operations took place when going astern, the cam being arranged suitably for each direction of rotation. In order to provide for possible stopping of the engine on a dead centre, cylinder No. 1 had also a hand-worked starting-valve, which gave a separate charge of compressed air sufficient to move the crank away from the dead point. Compressed air was supplied by a small single-cylinder auxiliary engine of about 4 B.H.P. direct coupled to a Reavell compressor, which discharged into a receiver of sufficient capacity to provide for about eight reversals with the auxiliary engine stopped. With the engine going ahead and astern as quickly as was likely to be required in any emergency, the auxiliary engine and compressor was sufficient to maintain the full air-pressure in the reservoir. The maximum time required to go from full speed ahead to full speed astern was found to be 10 seconds, the time being taken from the giving of the order to the moment the engine was well started. The average time of several trials was $7\frac{1}{2}$ seconds. That engine worked satisfactorily, but of course it was only 80 B.H.P., and it was

a far cry from 80 HP. to 1,000 HP. The first question was: Why was Mr. Anstey. there a difficulty about reversing? The ordinary standard engine of commerce—the engine that a maker sold like a pound of sugar—would run in either direction. What, then, was the difficulty? He thought it was summed up in two things—perfection of detail and reliability of ignition. The system might be the best in the world, but if there were defects in some points of detail, if some things were overlooked, the whole thing would be a failure. With regard to reliability of ignition, when the engine was started by the motive power, whatever it was, it was necessary to make absolutely certain that the cylinders did pick up the ignition at the proper time and so carry on the work which had been initiated by the starting-devices.

Figs. 10.

The engine he had described fulfilled the Author's conditions (a) and (b); it was also capable of running at reduced speed. The full speed was about 500 revolutions per minute, and it had been at speeds between 140 and 160 revolutions per minute in the boat without stopping. He had not any diagrams from that engine, but *Figs. 10* were from a similar engine. It would be seen that the full-load card showed a mean pressure of 65 lbs. per square inch. Running the engine on a brake load at one-third speed, carrying one-ninth of full load, that was to say, one twenty-seventh of the full brake horsepower corresponding with what the engine would do in the boat at this reduced speed, the mean pressure was 26 lbs. per square inch: the mean pressure at reduced speed was therefore 40 per cent.

[THE INST. C.E. VOL. CLXVIII.]

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Mr. Anstey. of the mean pressure at full speed. According to the Author's calculation it should have been possible only to reduce the speed to 63 per cent. of the full speed. He was somewhat surprised at the Author's figures, because he knew his reasoning was sound; but he thought there were two points the Author had not taken into consideration. The engine he had described had a fly-wheel, but a very small one—on a land engine it would be called ridiculously small—and the turning-moment was certainly not good, due to the arrangement of cranks adopted for starting and reversing. The two points were as follows. First of all, the resistance of a ship varied as the square of the speed, and therefore it was the effective power at the propeller which varied as the cube of the speed, and it was the mean pressure corresponding with the effective power which should vary as the square of the speed. It was customary in connection with steam-engines to consider that the effective power and the indicated power were more or less in a constant ratio, and no doubt that was approximately correct; but in an internal-combustion engine, as the load was reduced he thought it probable that the mechanical efficiency fell off, and consequently there was at reduced speeds a higher mean pressure than would be expected from the effective power which was being transmitted. The second point was that when the boat was under way there was a considerable stream of water flowing past the propeller, and that tended to keep it revolving, even though the turning effort momentarily fell off. He quite admitted that that was not a thing to be relied upon, because in a seaway, if the vessel were hove to, the sea would probably be striking the propeller, and, with an inadequate turning-moment, the engine might be brought up all standing: therefore it was very necessary and desirable to secure an even turning-moment. He agreed with Lieut. Sillince that a six-cylinder single-acting engine would be most likely to give the best results. The Author had given an idea of what power was possible in a gas-engine, and Mr. Anstey would like to mention what was possible in a large oil-engine. In the development from 80 to 1,000 B.H.P. many details would have to be worked out—details which would be quite different in the large engines from what they were in the smaller ones. The largest power yet attempted in a single cylinder was about 160 to 200 B.H.P., and he believed there were only two types of oil-engine in which this had been achieved, the Hornsby, which he had described, and the Diesel. Six of those cylinders would give about 1,000 H.P., and if the ship was a twin-screw ship 2,000 B.H.P. would be obtained, which would give a ship of about 5,000 tons or 6,000 tons displacement a speed of 12 knots. The space required would be an

engine-room about 33 feet long and 26 feet wide, with head-room of Mr. Anstey. probably 15 feet or 16 feet from the centre-line of the shaft. Of course, such an engine would take some time to work out. There were two factors, time and cost; but he had no doubt that some time or other a start would be made on those lines, and an engine would be produced which would be a success in every respect.

Mr. R. W. A. BREWER considered that the most important point in Mr. Brewer. the problem was the production of an explosive mixture. The solution of the problem of generation of power when that mixture was produced was very far advanced, but the question of the fuel to be used for marine purposes still required considerable study. He could see only one solution at the present time, and that was the adoption of a heavy oil—the residuals left after the lighter fractions had been distilled off. The heavy oil should be what was left after about 350° F. had been attained in the distillation process. With regard to the quantity of that kind of fuel available, he had figures which showed that the production from the world's oil-fields in 1906 amounted to about 30 million tons of crude oil. Under the present standard only about 1 million tons were distilled off at a temperature below about 212° F., and if that standard were altered, as it was hoped it would be within a measurable time, the total quantity of the lighter residuals which would be distilled off would only amount to about 3 million or 4 million tons per annum. The heavy residual oil would be in no way dangerous when used on board ship. Every other system that had been proposed—gas-producers and so on—was attended with serious risk on board ship, in addition, of course, to the weight which such parts of the machinery must necessarily have. The advantages of storage and manipulation attending the use of liquid fuel were well known, but with internal-combustion engines there were many other considerations. Up to the present, the great disadvantage of the use of liquid fuel had been the extreme difficulty of measuring exactly the small charges that were necessary for use in an internal-combustion engine. It might be taken that the system of measuring exactly each individual charge was the only system that could possibly succeed when used on that scale. The conditions which obtained in a small engine did not obtain to the same extent in a large engine, because the amount of oil required per charge was considerably greater; the measuring apparatus could therefore be more crude, and any wear of the working parts would not affect the result in the cylinder so much as it had done in using the same system on a smaller scale. He did not see any great difficulty in designing and producing a large

Mr. Brewer. oil-engine; and from the figures he had given he felt sure that a large supply of fuel was available. A previous speaker had doubted that, but the figures Mr. Brewer had received from a very reliable source showed there could be no doubt as to the supply of that fuel. There was also another important thing from the point of view of the motorist. At present people using liquid fuel were largely in the hands of the controllers of the supply. The chief reason for the handicap in that direction was the distillers' difficulty in getting rid of the residuals. By opening up an extensive market for heavy residual oil, some co-operation could easily be arranged between users of products of petroleum in every form, and that point alone was important. The supply of liquid fuel would be controlled to a very large extent, and the price of the fuel would be fixed. For that reason alone the use of liquid fuel should receive careful consideration at the hands of those who were engaged in the design of large internal-combustion engines.

Sir William White.

Sir WILLIAM WHITE, K.C.B., Past-President, observed that the discussion so far had been in the hands of those who had to do with the designing or working of the machinery, but what he wished to say would be from the point of view of the men who had to design and build the ships in which the engines had to work. It was well known that he was among those who looked upon the extended use of the internal-combustion engine for marine purposes as not merely a probability but as a thing which, starting perhaps on a small scale, must grow. To what extent it would grow, no one could quite foresee at present; but considering the comparatively limited time the application of the internal-combustion engine had been proceeding, remarkable progress had already been made, and much information had been obtained as to the best lines of advance. In his Presidential Address 3 years ago he gave certain facts as to what had been done in the way of applying internal-combustion engines to the propulsion of small vessels;¹ but since that time much more had been done, not merely in the scale of operations but in the variety of the experiments made. The general impression made on his mind by the remarks in the discussion, especially those of Mr. Dugald Clerk and Professor Burstall, was that in the application of internal-combustion engines to the propulsion of ships there would be many difficulties on the large scale which had not been of serious importance hitherto; and that those highly experienced men did not look forward with confidence to the immediate advance of the internal-combustion engine to large powers for marine purposes.

¹ Minutes of Proceedings Inst. C.E., vol. clv, p. 42.

That opinion was an important one; but he had gathered in subsequent conversation that Mr. Clerk did not mean to convey the idea that the difficulties to be faced were insurmountable; and that was a very important fact. To the conditions which the Author had stated (from the point of view of a marine engineer) as necessary to be fulfilled in a successful marine engine, he would like, as a naval architect, to add two or three others, which in the practical application of the internal-combustion engine to ship-propulsion would have a very important bearing upon success or failure. For example, there was the question of safety when such engines were fitted in the confined spaces that were unavoidable in the engine-rooms of ships. It was said that there ought not to be leakages, that there ought not to be formation of explosive mixtures—in fact, there ought not to be anything to conduce to accidents; but as long as machinery was not absolutely perfect, and as long as the human element was not always consistent or efficient, he presumed that conditions which might tend to accident would exist, and undoubtedly would have to be guarded against. It seemed to him that, in any application of the internal-combustion engine in a confined space, it should be of the essence of the design that with ordinary care and management there should be no accumulation of gas such as could possibly form an explosive mixture. Reference had been made in the discussion to the question of the rate of rotation, and the questions he had put to Dr. Hele-Shaw with regard to the beautiful little engine he had exhibited had been asked advisedly, because power was not put into ships simply to show the triumph of the mechanical and marine engineer, but was put there to propel the ship economically and efficiently. An engine working at a very high rate of revolution and giving a very poor efficiency of propulsion would be highly unsatisfactory to the shipowner, or to the person who had to design the ship. Sometimes there was a tendency to separate the question of the efficiency of the motor from efficiency of propulsion, which included, of course, the efficiency of the propeller.

Professor HELE-SHAW said he had meant working through gearing. Professor Hele-Shaw.

Sir WILLIAM WHITE remarked he was very familiar with the processes of reduction that were contemplated. The rate of revolution, however, had such an enormous effect upon weight and space that it must of course be taken into account. Many things might be done in a small vessel that could not be done in a large ship; many things might be done in an open space that could not be done in a confined space; and many things that could be done with perfect propriety in a Sir William White.

Sir William
White.

motor-car could never be done in a ship. As to what could be done in a flying-machine he spoke with no authority at all. When a man embarked on such an enterprise, the small details of the efficiency of an engine or the escape of a little gas hardly counted. Those were points which were of great importance in the application of internal-combustion engines for marine purposes. Of course space and weight, and weight of fuel for a given voyage, were matters which the ship-designer had to put in the forefront of his work. In all that had been said in the discussion he had not been able to gather any specific information whatever on any of those points. It might be that the information did not exist. Perhaps it was asking too much at present to require particulars of internal-combustion engines of large power such as would be used in ships. The question of the practical application of gas-engines of large power to ship-propulsion could not possibly be dealt with at the present time; and he was sure the Author would agree with him in that. He was quite aware that before that information could be given to the ship-designer experiments must be made on many machines in order to obtain data that would be a guide for the estimates given by the marine and mechanical engineer to the naval architect. Of course there were in the world people who did not feel that difficulty. Two years ago he studied with great interest, but not with that conviction which the writer intended to produce, a design for twin-screw gas-engines aggregating 10,000 HP. The writer of that article produced an elaborate drawing showing the design of the engine in detail, and gave an estimate of weight and an estimate of its rate of fuel-consumption. It was a producer gas-plant, and he gave everything that could be desired; indeed, he was prepared to go to the second place of decimals! But the article did not carry to Sir William White's mind the conviction which would be necessary before he put his name to a design embodying that machinery. No doubt the inventor was quite convinced that it could be done; but, knowing what he did of the largest gas-engines produced up to that time, all Sir William could say was that the inventor had the courage of his opinions, but was certainly not likely to get many customers to purchase the engines which he was so ready to design. It seemed to the speaker, notwithstanding what had been said by Mr. Brewer respecting the use of oil for marine purposes, that the question of internal-combustion engines came back to the question of the use of producer-gas. It had been said that the residuals left after the distillation of oil were difficult to get rid of. Speaking from personal knowledge, he could say that, when an attempt was made to put into the form of a binding contract any arrangement

for the purchase of such residuals for fuel there was the greatest difficulty. High authorities—perhaps as high as any the last speaker had quoted from—had told him in the course of general conversation that there was no difficulty whatever in guaranteeing almost unlimited supplies at very moderate prices; but those same high authorities, when it became a matter of contract extending over a definite time at a fixed rate, were not ready to commit themselves. He thought it would be found, if the matter was looked into, that the position was still very much what it was about 12 or 14 years ago, when the Italian Government—which had no preference whatever for coal over oil as a fuel, because Italy produced neither—having sent a most capable commissioner to study the matter on the spot in the oil-producing regions of Russia and America—came to the conclusion that the visible supplies of the residual products of distillation of petroleum were altogether inadequate for the supply of fuel for marine purposes, even for the trade of the Mediterranean. Since that time there had been a large increase in the production and in the uses of petroleum; and he was convinced, after close study of the subject, that it was not possible to depend, under commercial conditions, upon the visible supplies of residual products of petroleum distillation either for fuel or for extensive use in oil-engines of the mercantile marine—or even a small fraction of the mercantile marine—of the world. No doubt it was perfectly true that, as an auxiliary to coal, oil was of the greatest value. The Italians had proved that long ago: they had threshed the thing out completely by their own trials, and they had rested upon the conclusion that oil must be looked upon as an auxiliary, and not as a substitute for coal. If that was true, then it was not possible to consider the question of the use of the internal-combustion engine in ships on a large scale without having resort to producer-gas. That was his own feeling at the present time. He did not say it was always going to be true; but if there was to be any large application of gas-engines on board ship under existing conditions, it seemed to him it would have to depend mainly on producer-gas. Therefore, if the matter was to be taken up in a practical fashion on a large scale, the perfecting of the gas-producer, to which Lieut. Sillince had alluded, and which was already in hand, would lie at the very foundation of any great or general progress. Of course that would mean gradual experiment and gradual development, and that was of the essence of the problem. No one would be wise to make a great step without assuring himself of reasonable prospects of success. Dr. Hele-Shaw had spoken of the “Turbina” and her performances, of what was said about them at the time, and of what

Sir William
White.

Sir William White. had since happened. That was perfectly true; but while it was true in principle, there were many conditions in which the parallel did not hold; and he thought Dr. Hele-Shaw would agree that that was so. He himself was all for progress, but he was also convinced that it was necessary to proceed with care; and he was of opinion that the best results would be obtained when it was possible to get those who had had extensive experience in the construction of gas-engines or internal-combustion engines for other purposes to work with marine engineers in attempting to carry to a successful issue that particular application of the internal-combustion engine which had been under discussion.

Mr. May. Mr. JOHN MAY observed that, although he was not a marine engineer and knew little about gas-engines, he had been struck by the conditions that were set down in the Paper as necessary for a successful marine engine. The speakers at the opening of the discussion had shown how imperfectly the gas-engine was adapted to meet those conditions, but in all probability they had been drawn up having regard to the present practice with steam-engines, and on the assumption that there must be a direct drive from the engine to the propeller. Some little time ago a similar problem was attacked in Russia. As the result there were at the present time two boats on the Volga driven by oil-engines; but the propellers were driven through electromotors and not directly. A little thought would show at once what a wonderful revolution that would make. If it were possible to introduce electric driving, all the difficulties would disappear. First of all the starting, stopping, and reversing would be perfectly controlled. Then the number of engines could be varied; instead of having the monsters so many people were nervous about, it was possible to have as many smaller engines as were necessary and to put them in any part of the ship. There was further no need to run the gas-producers in parallel; a separate producer could be used for each engine. Altogether, the electrical combination would be almost an ideal combination, except for the extra weight and the small loss in transformation. It seemed that the advantages of the electrical drive were so great, and dove-tailed into the gas-engine problem so perfectly, that it ought to be considered whether it would not be feasible to adopt the electric drive in spite of its drawbacks. Another point arose with regard to water. On land gas-producers used a great deal of water, and he would like to ask whether salt water would be an acceptable substitute for the water used for cooling the engines and for the scrubbers. Suction gas-producers needed about 2 gallons of water per brake horse-power-

hour, and it would be impossible to get that at sea except by using Mr. May. salt water. He also wished to know the amount of fresh water necessary for the producers. Even if salt water could be partially used it could not be used for all purposes. With reference to Mond gas, his only experience had been a very unhappy one. It occurred in connection with a producer for which it was claimed that no elaborate washing-appliances were necessary. The producer was put up and the engine had not been running more than a few hours when the valves were taken out with a beautiful glossy surface as though they had been japanned. The Mond producer owed its success largely to the ammonia-recovery process, the gas receiving such thorough treatment in going through that it came out clean; but when the gas was taken straight from the producer there was trouble at once, to judge from his experience.

Mr. ALEX. SIEMENS called the last speaker's attention to the fact Mr. Siemens that to drive ships by electricity would necessitate first having a gas-plant powerful enough to drive the ship, then an electric generating-plant strong enough to drive the ship, and then electric motors sufficiently powerful to drive the ship. The weight would render it absolutely impossible to drive a ship by electricity in that way.

Mr. MAY pointed out that a much higher speed of revolution could Mr. May. be used for the engines.

Mr. SIEMENS maintained that he was right. He had studied the Mr. Siemens. matter thoroughly in connection with a Paper on the subject which he had read before the British Association at Dover.

Mr. W. W. TONKIN remarked that many years ago he had a great Mr. Tonkin. deal of experience with gas-engines, working with the two-stroke cycle of the kind described by the Author at p. 125. This engine had one single-acting cylinder, the explosion taking place only at the back end of the cylinder, the front being closed and used for compressing pure air into a reservoir. The coal-gas was compressed separately, and the gas and air were mixed in the valve as they passed into the cylinder for a certain portion of the stroke, and then cut off, ignited, and expanded during the rest of the forward stroke, and the whole exhausted during the return stroke. The cycle was similar to the Author's proposed cycle. With this engine it had always been found possible to start, even with half load on, by opening the stop-valve and admitting the compressed air left in the reservoir from the previous day's work, the engine being relieved of the work of compression for a few strokes by tripping the air suction-valve. With a number of cylinders, starting would be still easier. There were, however, other important advantages of this proposed two-cycle gas-engine, which had not been mentioned by the Author. Chief

Mr. Tonkin. among these was the possibility of varying the power of the explosion to any extent, promptly and economically. Referring to *Fig. 7* (p. 122), theoretically the rise of initial pressure from D to F, as also the work done during the subsequent adiabatic expansion from that pressure, should be in exact proportion to the amount of heat supplied, the efficiency remaining the same for all initial pressures and powers; but when the heat was obtained from an explosive mixture there were narrow limits below which the mixture burned too slowly, or failed to ignite at all. He had placed some diagrams on the wall, of which *Fig. 11*, taken from an old four-stroke gas-engine many years ago, showed the effect of weakening the gas mixture by varying the period of gas-admission from full stroke down to 60 per cent. of the stroke by a cam with six steps. *Fig. 11* showed that the power was

Fig. 11.

varied fairly well, but the economy was very low. On cam 5, admitting gas for 75 per cent. of the stroke, only 28 per cent. of the full power was obtained; while on the lowest gas-admission of 60 per cent. (cam 6) only a small explosion was shown towards the end of the stroke, and the gas burning during exhaust always fired the next charge. This method of varying the dilution of the charge was still in use in large gas-engines, in cases where steady driving was of more importance than economy; but it seemed to him that any arrangement of this sort was unsuitable for marine purposes. In order, therefore, to make use of the theoretically perfect method before referred to, of governing gas-engines, it was evident that

some means must be found of introducing into the cylinder varying quantities of gas-mixture of constant strength, and kept separate from the rest of the contents of the cylinder. After many experiments in glass cylinders, with smoke to represent gas-mixture, he

Fig. 12.

Fig. 12^a

had been able to get the results sketched in *Fig. 12*. Pure air entered by a port next the inner wall of the cylinder, and the smoke by a port in the centre, forming a central core of the shape sketched, the size of which could be varied by throttling the centre port. *Fig. 12a* represented the smoke-cone when only a small quantity

Fig. 13.

passed in, the rest of the cylinder being filled with air. When applied to a gas-engine cylinder, this arrangement was completely successful, it being found possible to reduce the power of the explosion to any extent and in proportion to the gas-supply. *Fig. 13*

Mr. Tonkin. showed four superposed diagrams taken from this engine at different powers illustrating the effect of varying gas-supply, and in all cases the ignition was prompt, only the height, and therefore the power, varying with the gas supplied. The amount of gas-mixture in the centre was varied by a throttle-valve, the rest of the cylinder being filled with air under compression. *Fig. 14* showed the complete full-power diagram No. 1, the compression-curve being shown on the left, and the admission and explosion on the right hand. In comparing *Fig. 14* with the four-stroke-engine diagrams shown in *Fig. 11*, it was only necessary to take the explosion portion of the former diagram, measured from the top expansion-curve F G, *Fig. 14*, down to the expansion-curve D B,

Fig. 14.

which would be drawn if there had been no explosion. Working out in this way the power of the explosion for the four diagrams shown in *Fig. 13*, and calling the power and gas-consumption for No. 1 diagram 100 per cent., then diagram No. 3 gave 78 per cent. of the power with 83 per cent. of gas; diagram No. 5 gave 52 per cent. of power from 54 per cent. of gas; and diagram No. 7 gave 27 per cent. of power from 28 per cent. of gas. The power was thus practically in proportion to the gas-supply within the limits of experimental error. The amount of gas required for a given power in this explosion-curve DFG B was found to be practically the same as for ordinary four-stroke engines; it depended on the ratio of expansion, and varied in the same proportion as in present gas-engines with hit-and-miss regulation. Another

advantage of the Author's proposed cycle was that it was possible to use a regenerator in the port leading into the cylinder, as in the case of a hot-air engine, and thus to obtain a considerable amount of extra power from the heat of the exhaust, which would otherwise be thrown away. The effect of heating the compressed air as it entered was to lessen the quantity drawn from the reservoir—the pressure in which therefore rose until a balance was obtained from the reduced volume discharged by the compression-pump at the higher pressure. This was shown in *Fig. 14*, where KL was the volume discharged, equal to EJ, which by heating was caused to expand and fill the volume ED. In *Fig. 14* the shaded portion JDBH showed the amount of power in this diagram gained from the action of the regenerator: the lower curve JH of the shaded part was the curve of compression, and the line DB the curve of expansion of the heated mixture without explosion, and the difference

Fig. 15.

was due entirely to the regenerator. In diagram No. 1, shown in *Fig. 14*, the power of the explosion-area, FGDB, was 5 HP. at 160 revolutions; the shaded portion below gave 1.6 HP., equivalent to a gain of 32 per cent. extra power from the same quantity of gas. Even after allowing for the excessive losses in this engine due to small ports and for the usual suction and exhaust losses, the net power of the whole diagram was 6 HP., showing a gain of 20 per cent. from the action of the regenerator over the ordinary power derived only from the explosion. The heating action of the regenerator was specially useful when using paraffin oil or poor gases. This kind of engine was therefore specially suitable for any case where it was necessary to reverse and go at different speeds. He had had the engine running unloaded at 36 revolutions per minute for an hour (*Fig. 15*), also at full power at 85 revolutions (*Fig. 16*), and it could be started and controlled at all powers

Mr. Tonkin. exactly the same as a steam-engine, and without a governor. He therefore agreed with the Author in thinking the time had come to reconsider the question whether it is not advisable to adopt a more suitable cycle for gas-engines than the present four-stroke cycle, to enable the gas-engine to compete with the steam-engine on more equal terms.

The Author. The AUTHOR, in reply, regretted that more had not been said from the marine engineer's point of view. Sir William White had justly said that in order to make progress in such a new departure it was necessary to get together the gas-engineers, or those who had

Fig. 16.

been used to internal-combustion engines and knew their peculiarities, and the marine engineers, who knew all the requirements for marine engines. Fortunately some of the gas-engineers had spoken, and they seemed to be under a similar impression; they said it would be desirable to know what a steam-engineer thought of a gas-engine. Sir William White had spoken as though it were contemplated in the near future that internal-combustion engines would be used in all ships, but he did not think that was ever contemplated.

Sir William
White.

Sir WILLIAM WHITE did not think he had said anything to suggest that.

The AUTHOR observed that there certainly were places where oil The Author. was a much cheaper fuel than coal, and in such places, if ships were wanted, it appeared to him that, instead of burning the oil in a steam-boiler and using its energy through the medium of the steam-engine, there would be a great field for an oil-engine pure and simple. That would save many things. First of all, there was no boiler to deal with. Mr. Anstey had mentioned that the space required for an oil-engine of 2,000 B.H.P. would be much less than the room occupied by an ordinary marine engine of the same power, let alone the boiler-space; and besides that there was a saving of bunker-space. If coal was used, it was necessary to carry coal for the whole of a voyage. Using oil as a fuel, even if there were no great advantage in the weight to be carried—which there was, even in using it as a fuel in boilers—a good deal of stowage-capacity would be saved, because oil could be put where coal could not. It must therefore be admitted that there were many places in which oil was being used as a boiler-fuel, where, if an internal-combustion oil-engine could be used, it would be of great advantage. Professor Burstall was perhaps rather severe. He seemed to think that it was not possible to make a large vertical internal-combustion engine. He did not say, however, why the vertical engine could not be employed. As a matter of fact, vertical gas-engines had been used very successfully in many places, although perhaps not of so large a size as some of the large horizontal engines. After all, he did not think the question of vertical or horizontal should come into serious consideration, for if a horizontal engine was practicable, and a vertical one was not practicable, it was only necessary to look back for a few years to find horizontal engines on board ship and working very successfully. The vertical steam-engine had come into general use on ships because as a whole it was a better engine than the horizontal, but it was not essential that marine engines should be vertical. Again, Professor Burstall and others seemed to be wedded to the four-stroke cycle, but the Author himself thought the two-stroke cycle was likely to meet the requirements of marine engineers very much better than the four-stroke, principally because it gave a greater range of adaptability of speed, and presented no difficulties whatever in reversing. The worst Professor Burstall had said about the two-stroke cycle was that it could not be so economical as the four-stroke. If the figures were correct that a four-stroke cycle engine was working on 0·7 lb. of common coal per indicated horse-power-hour, there was such a margin between this and the best marine practice with steam-engines, that even if another engine were made which had no mechanical difficulties, but which did not give quite so much efficiency as the four-stroke cycle,

The Author. it would be still a long way beyond the steam-engine. The strongest criticism of Mr. Dugald Clerk against the two-stroke cycle was that it was liable to back-fire. In the engine proposed there would be no question of back-firing, because the air and the gas would be compressed separately; and if an oil-engine were used instead of a gas-engine, there would of course be no question of back-firing. The question of safety had been raised by Sir William White, and the safety of the men working in the engine-room was of course a vital matter; but, in case of accident, his own impression was that an oil-engine was a safer engine to be alongside when it was breaking up than was a steam-engine. Because a four-stroke cycle was, on the whole, the best to be employed on land, it by no means followed that it would be better than the two-stroke cycle for marine work. The four-stroke-cycle engine required either a large number of cylinders or a large fly-wheel, and it also needed two-to-one gearing for its valves. Both fly-wheels and gearing were very undesirable in marine engines. The four-stroke cycle presented more difficulties than the other in the way of reversing, whilst the two-stroke-cycle engine permitted of the necessary variation in speed, which could not be obtained in the four-stroke-cycle without the employment of a larger number of cylinders than was really required for the maximum power. The multiplicity of cylinders advocated by Dr. Hele-Shaw was very undesirable at sea. Mr. Anstey had pointed out that the mechanical efficiency of an oil-engine fell off rapidly with the decrease of the load. This was no doubt due to the fact that the constant friction of the engine operated on all four strokes of the cycle, whereas the forward pressure operated only on one. In this respect, therefore, it would be expected that the two-stroke engine would not show such a falling off, and possibly also for the same reason the two-stroke engine would show a greater efficiency than the other at all powers. Professor Burstall feared that in a large cylinder with a two-stroke cycle the water-jacketing would not keep the cylinder-walls sufficiently cool. This was a matter to be determined by experience. In this respect it was worthy of notice that large Körting engines, which worked on a two-stroke cycle with separate air- and gas-compression, were still being made in Germany. It seemed, therefore, that the anticipated trouble did not exist. Condition (*b*), namely, that of prompt starting, had not received much attention in the discussion. Mr. Anstey had explained that, in his small four-cylinder four-stroke-cycle engine, he obtained complete command in this respect by having three out of the four cylinders actuated as two-stroke-cycle air-engines, leaving the other cylinder to act as an

internal-combustion engine. It was to be noted, however, that his engine had necessarily to be fitted with a fly-wheel, which was out of place in a large marine engine. In conclusion, the Author believed that, as stated in the Paper, the best solution of the problem of internal-combustion engines for marine purposes would be found to lie in the adoption of a two-stroke-cycle engine with three double-acting cylinders and three cranks, using separate air- and gas-compressors independently driven.

Correspondence.

Mr. A. C. HOLZAPFEL observed that the Paper suggested rather an ideal engine, an engine which ultimately might be evolved out of a large amount of further practice, but the adaptation of which at the present moment would offer almost insuperable difficulties. As regarded his proposal for separate compression, this had been in use by the Messrs. Körting, of Hanover, for many years, but these engines were not successful: from what Mr. Holzapfel had learnt they had not in practice been so economical or so perfect as theorists had claimed for them; so that when he visited the works of Messrs. Körting about 2 years ago he found that nearly all the engines they were then building were of the four-cycle type. From inquiries which he had made of many practical and scientific men, he had no doubt that the best engine to be adopted in the first place for marine work would be the four-cycle engine, and that it would be desirable to have a number of cylinders of comparatively small diameter, preferably about a dozen. It would be desirable to have these engines with cylinders mounted tandem fashion, that was, twelve cylinders with six cranks. Such engines, of course, would take up considerable space longitudinally, but this need not increase the amount of space now allotted in modern vessels for propelling purposes, as the gas-generators could be fitted at the sides of the engines. Personally he thought it would be best in the first engines to use only anthracite coal, although his firm had had in very successful use on land, for more than $2\frac{1}{2}$ years, a 500-HP. Mason gas-plant using bituminous coal. He thought it would be risky to put in charge of steam-trained engineers, not only an engine but also a gas-generating plant of entirely new design; in fact, this was essentially a case where two bites should be taken at the cherry. The Author did not refer to the work which had been done by Mr.