9.

SOME ASPECTS OF THE INTERNAL COMBUSTION ENGINE.

The internal combustion engine assumes increasing importance from day to day, and a knowledge of these machines is necessary to all marine engineers irrespective of whether they have running charge of such engines or not. There is now in existence a large number of different types of such engines, each having its own particular uses and characteristics, and all working on one or other of the few known cycles. The rapid development of these types of machinery in the mercantile marine not unnaturally raises the question of the use of similar prime movers for naval purposes and the possibilities in this direction are not infrequent subjects of discussion. The leading considerations in this connection are, of course, within the knowledge of most engineer officers, but a brief and elementary account of these may none the less be of value, and will, it is hoped, serve as a ready means of reference. The subject is fraught with many ramifications, and, as a convenient method of dealing with it, this paper commences with a number of general questions, to which the answers are subsequently propounded. The answers to these questions are, however, mutually interdependent in many cases, and it is not therefore practicable to separate them completely: the general order in which they are initially placed has, however, been observed as far as possible in the subsequent discussion.

(1) What is the maximum H.P. that can be obtained from a cylinder of given size?

(2) Which is preferable, air or airless injection, 2 or 4-stroke cycle working?

(3) Why is the double-acting engine not more largely fitted?

(4) What is meant by supercharging; what are its limits and what effects follow its application?

(5) Why is the Diesel engine so heavy for its power when the internal combustion engine of another type is so easily our lightest prime mover?

(6) What are the expectations of the Diesel engine supplanting steam turbines and boilers in the Naval Service?

(7) What hinders the development of the internal combustion turbine?

(8) Why are the marine Diesels constructed by British firms almost invariably labelled with foreign names, Burmeister & Wain, Sulzer, &c., and made under foreign licence?

and so on.

Taking the question, " What is the maximum power that can be obtained from a given size cylinder?" Before the answer is attempted, one must be clear on a certain point, namely, that the working substance in an internal combustion engine is air and not oil. As in the steam plant, so here also, the oil is the substance employed for the generation of the heat energy, but in neither case is it the working substance. The internal combustion engine is a hot air engine in which the heat is applied in the cylinder by the combustion of the fuel. It is true that the working substance changes from air to products of combustion at a certain stage, but these latter differ little from air as regards their main properties. In any case the argument is not affected by this change.

Now, in a definite weight of air, it is only possible to burn the amount of fuel that can chemically combine with the oxygen present. Theoretically, 1 lb. of fuel such as is used in Diesel engines requires approximately 15 lb. of air for combustion. The weight of air entering the Diesel engine cylinder during the suction stroke is a fairly well-defined quantity bearing some relation to the stroke volume, and thereby the amount of fuel that can be burnt is decided and hence the maximum amount of heat that can be generated. Working from this basis, and knowing that with the unavoidable losses to the jackets and to the exhaust, a good engine over wide ranges of power consumes, say, ·32 lb. of fuel per I.H.P. per hour (·4 lb. per B.H.P. per hour is a frequently quoted figure with which all engineers are probably familiar), it can be shown that providing the stroke volume before compression was full of air at atmospheric temperature and pressure, the mean pressure with full utilisation of this air would be about 220 lbs. per square inch. The proof of this is not difficult, it follows from the figures quoted.

Such a pressure is not, however, realisable in practice; it is discounted by two effects, viz., the fact that the volumetric efficiency of the engine is less than unity, and, secondly, the necessity for an excess of air over that theoretically required for combustion of the fuel. The engine cannot induce a charge equal in weight to that of a cylinder full of air at atmospheric pressure and temperature, because not only is the cylinder hot and the air thereby heated on entry, but also hot products remain in the clearance space: moreover, the pressure must be slightly below atmospheric in order that the air may enter the cylinder in the short time available. The air charge is therefore reduced in weight, and is about 80 per cent. of what has already been assumed. The possible maximum pressure is therefore reduced to 176 lbs. per square inch.

It is known that in steam boilers in order to obtain complete combustion, it is necessary to supply about $1\frac{1}{3}$ to $1\frac{1}{3}$ times the weight of air theoretically required. This necessity also obtains in Diesel engines. It is impossible to spray every particle of the fuel so that the whole of the air can be fully utilised. Experience shows that under the best of conditions there should be about

20 lbs. of air per lb. of fuel instead of 15. The possible maximum pressure, therefore, falls to 132 lbs. per square inch.

(NOTE.—The figures given must not be taken as mathematically consistent: they are sufficiently accurate, however, to enable an idea to be obtained of the order of the maximum pressure possible.)

When air is used to inject the fuel, the total weight of air is increased, and in the normal case it is fair to take about 10 per cent. increase on the above figure, *i.e.*, 145 lbs. per square inch, as the maximum possible mean pressure. It will be sufficiently accurate in the general case to assume, therefore, that the pressure will be somewhere between 130 to 150 lbs. per square inch as forming a basis for our possibilities. In any quoted cases of a Diesel engine obtaining higher mean pressure than 150 lbs., the reason is explained by a heavy blast air supply or a supercharge, or in the case of a small engine a possibly better utilisation of the air charge. Petrol engines have exceeded in some cases the above figures, but conditions are here more favourable for the intimate mixture of the air and fuel, and while in any case combustion difficulties are not so pronounced with the "explosive" oil. 125 to 130 lbs. mean pressure referred to the B.H.P. represent very good figures in the best aircraft engines, so that figures of a similar order are applicable for developing the argument.

At this stage it should be appreciated that with such pressures heat stresses are under control and the possibility is not limited by such considerations. To put it plainly, if not quite accurately, the mean pressure is limited by *chemistry.*

Having defined a mean pressure limit, it is necessary to consider the mean piston speed, since power is force multiplied by distance run in a given time. As far as this factor is concerned, it is not possible to lay down a definite limit from any physical considerations. Piston speed, however, governs such features as valve design, *i.e.*, the proportions of valves and power for operating them, inertia forces, wear and tear of piston rings, &c., and from such mechanical considerations it is usual to find in practice that certain limits are not usually exceeded, *e.g.*, in merchant service vessels it is generally less than 1,000 ft. per minute. In Naval practice it varies from 900 to 1,500 feet per minute, the latter figure having been attained in one instance only, and being unlikely to be adopted as a general standard at present. Speeds of 2,000 ft. per minute and over have been reached and exceeded in aircraft engines. An upper limit of 1,500 ft. per minute may be provisionally taken as the maximum piston speed reasonably attainable in Diesel engines of considerable power. On this basis, and with a maximum mean pressure of 150 lbs. per square inch, it can be shown that the maximum I.H.P. obtainable in a given cylinder in an engine working on the 4-stroke cycle is $1\frac{1}{3}$ D^2 approximately where D is the diameter of the bore in inches. Thus, assuming a mechanical efficiency of 75 per cent., this reduces to the simple law of D^2 B.H.P., *i.e.*, from a 20-in. diameter cylinder the maximum possible B.H.P. is 400. This figure could hardly be aimed for in a design at the present moment, and even in the most highly-rated engines in the service the designed mean pressure, piston speed and mechanical efficiency fall below the above-stated limits.

As regards a double-acting 4-cycle engine, similar arguments could be applied, *i.e.*, the maximum possible would be 2 D^2 B.H.P. approximately. At present, however, a more conservative estimate must be considered. The piston rod not only reduces the volume on the lower side of the piston, but it also affects the efficiency of the injection and the combustion. Moreover, in view of the fact that it has to operate through a gland, and mechanical difficulties arise in connection with the cooling of the piston, it would be safer at present to assume a maximum mean pressure of about 130 lbs. per square inch and a piston speed not exceeding 1,250 ft. per minute. This reduces the possibility to something like 70 per cent. of the above figure, *i.e.*, the maximum possible would be about $1 \cdot 4$ D^2. Such a figure cannot be taken as final, but represents the relation between what may be possible in a double-acting as compared with a single-acting engine operating on the 4-stroke cycle when working up to reasonable limits at the present time. It is safe to say, however, that the idea of doubling the power by double-acting is not possible in extreme cases. It might be noted, too, that the double-acting engine with its bottom cover, crosshead, piston rod and additional height, is necessarily a heavy engine, and hence its weight per H.P. may be no better than in the case of a single-acting engine. These reasons account largely for its present backward development in highly-rated units. If any great advantages in double-acting were realisable, it is reasonable to assume its development would have been more actively pressed in the field of aircraft engines, but, as is probably well known, the S.A. 4-stroke engine is the only type used. Even in the case of the more lowly-rated mercantile engine, where somewhat similar conditions as regards pressure and piston speed obtain in the two types, the advantage in weight saving is not very marked. Floor space may be economised, but height is considerably increased, this latter feature not being markedly objectionable, however, in merchant vessels.

So much for the 4-cycle engine. What of the 2-cycle ? Here again it is loosely argued that possibilities are doubled by the change, but one is immediately faced with the position that 2-cycle engines are not seen in aircraft practice, whilst in the merchant service it is known that such engines are at least as heavy as those of the 4-cycle type power for power. There must be reasons for this, and they are not difficult to appreciate.

All modern 2-stroke engines employ port scavenging. The exhaust ports are uncovered before the end of the expansion stroke and are not re-covered till the piston has returned a requisite distance. The length of such ports may be about 25 per cent. of the stroke. In other words, the effective stroke is only 75 per cent. of the actual stroke, *i.e.*, other things being the same, there is a reduced air charge. Moreover, the scavenging may not be as efficient as obtains in the 4-cycle engine where the exhaust gases are positively expelled by the piston; owing to the increased number of cycles, hotter conditions may obtain in the cylinder, tending to reduce the volumetric efficiency. In any case there are sufficiently strong reasons for assessing a lower limit to the maximum mean pressure obtainable. The speed of revolution is also a most vital factor in such engines, since exhaust and re-charging of the cylinder have to be carried out in about one-third of a revolution of the crank, hence the tendency is to work with lower speeds in 2-cycle than in 4-cycle engines. Again, power is required for the scavenging operation as the whole of the air required by the engine has to be supplied by external pumps or blowers, and this will increase the weight and space required for the installation over and above that involved by the power lines: the nett efficiency of the operation may well be less than that of the similar process carried out in the power cylinder of the 4-cycle type. It is unnecessary in this article to quote figures respecting possibilities, as so many conflicting features are involved. One must take things as they are, and with the above arguments accept them as the clues to the present definite inferiority of high-speed and high-power 2-cycle engines and to the absence of superiority of even low-rated engines of this type over their 4-cycle counterparts.

Passing to the double-acting 2-stroke engine, one can argue somewhat on the same lines as adopted in the case of the 4-stroke engines, remembering, too, that heat stress, especially in the case of the piston, is becoming a more and more vital factor in influencing the possibilities.

Sufficient has, however, now been said to enable it to be appreciated why the 4-stroke single-acting engine is still in a position to hold its own with other types on a weight basis when high outputs per cylinder become more and more a paramount feature of the design, as is the case in Naval engines and to the most pronounced extent in aircraft practice. Developments in the future may, of course, favour the double-acting engine, and the fact that a large amount of investigational work is being carried out renders accurate comparisons of no more than transient value.

So far, attention has been confined to engines which when acting on the 4-stroke cycle induce air from the atmosphere. To use an easily understood analogy such engines are operating under natural draught. Now, as in the case of boilers, the output can be increased by the use of forced draught as this enables an additional quantity of fuel to be consumed. Suppose therefore fans be installed to deliver the air to the engine cylinders under pressure, then obviously additional fuel can be burnt in the cylinders and the mean pressure increased. Such forcing is technically known as "supercharging" and the fans take the form of pumps or blowers. Now what are the possibilities of increasing the output by supercharging? Confining attention to the Diesel engine, it must be remembered that under normal conditions fairly high pressures obtain at the end of compression and during combustion, and the whole of the main details of the engine have to be designed to withstand this maximum pressure. It is not the power of the engine, but the maximum pressure, that governs the scantlings, and therefore the weight, of the details such as the covers, pistons, liners, framing, connecting rods, etc. In considering, therefore, the increase of output by supercharging, one must aim to keep the maximum pressure within limits, a figure of not more than 650 lbs. per square inch being a fair basis for Diesel engine design. This is somewhat higher than the pressure at the end of compression, which is of the order of 400 to 500 lbs. per square inch, depending on the method of fuel injection. Although the conventional Diesel cycle assumes combustion at constant pressure, it is found advantageous in practice to arrange for early injection of fuel and obtain part of the combustion at approximately constant volume so that the pressure rises to 600 lbs. per square inch, say. Such a departure from the strict Diesel cycle is known technically as the Dual Combustion cycle. In any case an engine which gives 500 lbs. at the end of compression and is designed for 650 lbs. maximum pressure can obviously be supercharged to the extent of giving 650 lbs. at the end of compression and the fuel injection delayed to secure combustion at constant pressure. In other words, the engine can be supercharged so that a pressure of $650/500 = 1 \cdot 3$ atmosphere reigns at the commencement of compression, *i.e.*, the air charge is increased, say, 30 per cent. The fuel consumed can be increased 30 per cent. and, other things being the same, the cylinder output increased 30 per cent., *i.e.*, the B.H.P. of the 4-cycle engine increases from D^2 to $1 \cdot 3\ D^2$. Power is, however, now required for the supercharge pump and discounts the output to some extent, but a gain of 15 to 20 per cent. should be possible. The extent of supercharging could be increased if higher pressures were permissible, but the weight of the engine then goes up. Supercharging to this extent has been demonstrated in actual engines and the aforesaid gain verified, *e.g.*, an engine of 20 in. diameter cylinder, giving a maximum mean pressure of the order of 150 lbs. per square inch, has yielded 200 lbs. when supplied with air from a blower at 5 lbs., *i.e.*, $\frac{1}{3}$ atmosphere gauge pressure.

An important point to note is that when an engine reaches its maximum pressure under normal conditions there is sufficient power in its exhaust to drive a turbo-blower which can supply the supercharge: further, as the supercharge comes on, this power is further increased and keeps step with the engine requirements. Provided this is practicable, the power for the supercharge requires none of the engine power and the whole gain in the cylinders is reflected in the net output of the engine. This at present has been practically applied in a few engines and is known as the Buchi system of supercharging, which is likely to be extended in its application in special cases. The turbo-blowers so actuated operate at very high speed and are comparatively small units.

A natural question arises in connection with supercharging, and that is, to what extent the heat stresses are increased and do they affect the limitations respecting its application? The answer to this is at first sight surprising. Supercharging does not increase heat stresses but may actually diminish them. This conclusion, which will be demonstrated from theoretical considerations, has been verified in all practical cases where it has been possible to secure the necessary data. The reasoning is quite simple. Due to the weight of the air charge being increased, it will not rise in temperature in the cylinder during its supply to the same extent as does a normally induced charge, *i.e.*, the temperature at commencement of compression will be less. The rise of temperature during compression is a function of the compression ratio, hence it finishes at a lower temperature in the supercharged engine. The fuel-air ratio being the same, the rise in temperature during combustion will be approximately the same and may even be much less in the supercharged engine, if the combustion is all at constant pressure. Expansion follows approximately the same law in the two cases. It is seen therefore that temperatures at corresponding points in the cycle (at least till ignition is completed) are lower in the case of supercharging, and the absolute heat flow to the details in contact with the hot gases will thus be but little altered. As, however, more fuel is burnt in the supercharged engine, it follows that the heat loss is a lesser percentage of the total heat generated; the efficiency is thus improved, while the exhaust temperature may be slightly higher. There may be a slightly increased loss in exhaust and a falling off in efficiency due to the delayed combustion, but on balance the efficiency will be little affected. Our final conclusion therefore is that output is increased by supercharging, its application is limited by pressure considerations, and there need be no increased heat stresses or reduction in efficiency. It might be pointed out that to secure the best effects the supercharge air should be cooled to atmospheric temperature after compression in the blower, the reasons being now sufficiently obvious.

Before leaving the question of supercharging, its application in the case of 2-cycle engines should be noted. Actually in such engines the scavenging is carried out under slight pressure but it is impossible to build up a pressure in the cylinder while the exhaust ports remain open. To obtain an advantage from such pressure Messrs. Sulzer arrange the scavenge ports in two tiers, the upper of which reaches further up the cylinder than the exhaust ports, so remaining open when the piston has just covered the latter on its return. This tier of ports is valve controlled so that the exhaust does not pass to the scavenge main when uncovered during the down stroke. It will be obvious, however, that to obtain any marked degree of supercharge in the case of a 2-cycle is not so simple as in the case of a 4-cycle engine and this increases the power of competition of the latter type in such cases where super-charging may be called for.

The question of method of injection of fuel into the cylinder of a Diesel engine often calls for discussion. There is the method of blast air injection and the method of pressure spraying which is referred to as solid, mechanical or airless injection, the latter term being more definite and finding greater favour in referring to such method. With air injection a compressor is necessary and this requires power, and a loss of efficiency in the installation would be expected. Air injection, however, gives better pulverisation and distribution of the charge and for highly-rated engines is at present advantageous. Except in small sizes it has hitherto proved difficult to design an airless injection engine which will give appreciably more than 100 lbs. mean indicated pressure, owing to the inefficiency of the combustion that has attended attempts to attain higher powers. If fine pulverisation be given the oil spray cannot penetrate the dense medium sufficiently far to mix with the air charge, whilst if given penetrative power, the spray is not sufficiently pulverised.

Summing up it may be stated that airless injection should be the best method of injection for engines rated not higher than 100 lbs. mean pressure, but for pressures above this air injection is necessary. Improvements may be expected in the future and most engine builders are experimenting with airless injection as it leads to the elimination of a unit which reduces to some extent the possible efficiency and which may considerably impair the reliability of the engine. Airless injection plants require separately driven compressors for charging the starting reservoirs but they are smaller than blast air compressors, while their use is intermittent. The commercial engine, apart from the Still engine, showing the greatest efficiency at present is the Doxford and this employs airless injection of fuel, the consumption being of the order of ·37 lb. per B.H.P. per hour. In the Still engine which adds a steam plant to conserve the heat rejected to the jackets and in the exhaust, slightly lower consumptions have been recorded : this engine employs airless injection.

Engineers are often reproached for not making effective use of the heat rejected in the exhaust and to the jackets. The fact that such a large percentage of the fuel heat is thus wasted is appealing, since the rejection is so obvious and, as far as the exhaust is concerned, it is fairly high-grade heat. In basing a reproach it is often argued that means should be found for converting this heat into energy by generating steam, but it should not be forgotten that when this is done about 85 per cent. of the heat so utilised is later to be rejected to a condenser. It is not proposed to describe the Still engine, but the possibilities of the system are worth reviewing. Of the fuel heat in the cylinder about 40 per cent. will be converted into work and 60 per cent. discharged. This 60 per cent. will be conserved in a regenerator and, with feed heating, steam may be formed at fairly high efficiency. Putting it at 75 per cent. this gives 45 per cent. of the fuel heat now stored in steam. Such steam can be used to supplement the power of the main unit or/and operate a turbine for the scavenge air (the Still internal combustion engine is 2-cycle) and drive the necessary steam auxiliaries. As only about 15 per cent. of this heat will appear as useful work the remainder being rejected to the steam condenser it means that 7 per cent. of the fuel heat is usefully employed and some of this is employed on an air-pump or auxiliaries that might otherwise not have been necessary. In any case the gain though appreciable is less than might appear at first sight possible. Forty-seven per cent. of the fuel heat is now usefully employed and an internal combustion engine which would use ·4 lb. per B.H.P. per hour should now show ·34 lb. per B.H.P. per hour, say, which closely approximates to what has been obtained in very favourable cases.

To obtain this increase of efficiency, however, it has been necessary to add a great deal of accessory plant, entailing increased upkeep and weight, and at present there is not a great rush on the part of shipbuilders, &c. to adopt this engine. Two motor ships so fitted are on service, and it is understood also that some locomotives are being constructed with such installations.

It is now necessary to consider why the high-power Diesel engine is so heavy for its power when the small size internal combustion engine can yield power in aircraft on an engine weight of less than 1 lb. per horse power. Merchant service engines weigh anything between 200 to 300 lbs. per H.P., usually more nearly approaching the latter figure, whilst the highly-rated engines in submarines may weigh about 50–70 lbs. per H.P. There must be reasons for this, and the differences will be easy to understand if a few facts be appreciated. In the case of an aircraft engine low weight is an important primary requirement, and increased weight cannot be generally tolerated unless it contributes towards endurance by enabling less fuel to be carried. It is considered by authorities on the subject that a cut-weight Diesel engine built on aircraft practice and of small size could be constructed to weigh about 5 lbs. per H.P. This higher weight than with petrol arises from the fact that mean pressures and piston speeds in such an engine must be rated lower than in petrol practice, owing to the impossibility of achieving the rapid injection and combustion of similar quantities of fuel. This 5 lbs. may serve as a starting point for considering the weight question.

Now, in aircraft practice the use of special materials and construction may render practicable the acceptance of stresses probably about three times as high as those usual with normal materials and design.

For example, where an aircraft engine uses an alloy steel for the crank-shaft, connecting rods, &c., the working stresses may be as high as 12 tons per square inch, compared with the 4 tons per square inch usual in other engines in which these parts are made of mild steel. The construction of the cylinders is another example of different practice; in aircraft these are turned from steel billets and have no liners, whereas the larger Diesel engines use cast-iron cylinders and liners; other differences will readily come to mind. Hence, if our light-weight Diesel engine were constructed of normal materials it will possibly weigh 15 lbs. per H.P. (It may be noted this is a common figure in motor-car engines which are built for endurance and which work to normal stresses.)

The use of special alloy steels is necessarily very largely restricted to the construction of small articles. This is due to the fact that in the present state of the metallurgical art it is not possible to guarantee homogeneity of the product when constructed of comparatively large masses of these high quality materials, many of which depend for their properties upon the results of proper heat treatment. The question of the cost of many such metals is another consideration of some importance.

The difference between 15 and 60 lbs. or 300 lbs. has now to be explained. This follows from the larger size of the Naval and commercial Diesel engines. It can be shown that with similar engines, say, a 5 in. by 5 in. and a 20 in. by 20 in. engine, if the same mean and maximum pressures be employed, and likewise the same piston speed, the power of the large engine will be 4^2 times that of the smaller and its weight 4^3 times as much, *i.e.*, the weight per H.P. goes up with the diameter. This is not absolutely exact, but is sufficiently so for purposes of general comparison. Take the liner as an example. Its thickness, circumference and length all increase as the diameter, *i.e.*, its weight as the $(\text{diameter})^3$. Similarly for the piston, connecting rods, cover, framing, crank pin and so on, this law approximately applies. It is therefore quite simple to understand a 20-in. cylinder engine weighing 60 lbs. per H.P. If the stroke were doubled a great part of the engine details double in length and therefore 100 lbs. would be approached. Lower the piston speed as in commercial engines to below the 1,000 ft. per min. and a further increase in weight can be appreciated. Use cast iron everywhere and accept lower stresses still, and so the 200–300 lbs. per H.P. can be understood, especially, too, as cylinders in large motor-ship engines may be 25 in. to 30 in. diameter. This reasoning is sufficient to enable the weight feature to be appreciated.

The next question is the possibility of the internal combustion engine as a propulsive unit for warships. This was fully dealt with in "Papers on Engineering Subjects" No. 7, and needs only brief reference. No matter what class of surface warship be considered, from T.B.D.s to capital ships, the power required per shaft is at present beyond the reach of the Diesel engine. Where it has been approached—say, 10,000 S.H.P. —the speed is low and the weight of the bare engine per H.P. is greater than can be accepted for the whole machinery installation on present requirements, even in the battleship class. No high-speed engines can yet be foreseen to approach this power, and even in tentative designs based on experimental work it is considered the weight and space required for the necessary installation of main and auxiliary engines would exceed that of the steam installation in latest ships. For classes other than the battleship the position is at present absolutely hopeless.

What of the internal combustion turbine? An article on the present position has recently appeared in these Papers, but the following remarks may serve to clear up many misconceptions. Many are inclined to consider on first thoughts that the advantages obtained from the use of the steam turbine as compared with the reciprocating engine will likewise follow with gas or oil turbines. The steam turbine scores over the reciprocating engine, however, by its freedom from cylinder condensation effects and by its ability to obtain the full effect of the expanding steam to a very low terminal pressure. These two advantages allow the turbine to obtain greater efficiencies than the reciprocating engine, but they are advantages special to steam and would not be reproduced in an engine using the working substance of an internal combustion engine. It is true that the gases in a reciprocating oil engine are released at some pressure greater than atmospheric, but the amount of additional power that could be obtained by utilising this wasted "head" is a much smaller percentage than that which follows from extending the toe of the steam pv diagram to the low pressures possible in actual cases. This is the first point that requires appreciation.

Now, it is a cardinal point in internal-combustion engines that, whatever the actual cycle, initial compression is absolutely necessary for efficiency, which in general increases with the ratio of compression adopted. It is also important to note that the change from reciprocating steam engines to turbines only affects a part of the steam system. Condensers, feed pumps and boilers are common to either type of prime mover. In the reciprocating internal-combustion engine the induction, compression, combustion and expansion are all carried out in the cylinder and the nett work obtained is the gross work represented by the combustion and expansion of the working substance minus the negative work involved in the compression, induction and exhaust operations, of which the compression is the major portion. It is possible to imagine an internal combustion engine in which the compression is carried out in one cylinder and the charge then delivered to the power cylinder in which the combustion will take place. It is likewise easy to conceive that such an engine would be very inferior to practical engines, in view of the addition of the extra cylinder and the serious losses that would be entailed, both mechanically in the compressor line and in effecting the transfer of the gas from one cylinder to the other. It is not too much to say that such an engine would be less efficient than many steam plants.

The internal combustion turbine needs some such arrangement as that just described. The turbine will only replace the power cylinder of such a combination, and hence this type of engine is handicapped from the start, although it may possess a few advantages over its reciprocating rival in other directions. The steam turbine starts with all the advantages of the reciprocating steam engine and adds others of substance, but not so the internal combustion turbine. It is this consideration, impossible to avoid, that in a large measure invalidates much costly experimental work and its development.

Quite apart from the foregoing, the problem of development is replete with practical difficulties in connection with nozzles and blading. Superheated steam at 700°–800° F. compels special attention to the blading, and it is not difficult to appreciate that blading subjected to the high-temperature gases resulting from the explosion or combustion of an oil charge will be likely to be in a poor condition to withstand stress and erosive effects. It cannot be cooled on the lines of those parts of a reciprocating engine which are exposed to the hot gases. It is not necessary to go any further; enough has been said to indicate that the internal-combustion turbine does not yet appear likely to enter into serious competition with prime movers of other types. Turbines driven by exhaust gases for accessory purposes, such as for supercharging, are practicable and are being developed, but as prime movers their position remains pretty well out of the question. A few machines have been constructed on the Continent, but the efficiencies are low.

The final question that was propounded in the opening remarks was, "Why do British firms construct in the main, marine engines of foreign design?" This at first sight appears a reproach to this country in which all-round engineering is looked upon as of a high standard, but it is not so when correctly viewed. Prior to the war there was a great incentive for continental firms to develop the Diesel engine owing to the lack of coal and its high price, as compared with that then ruling in Britain. The lead so obtained was in many cases lengthened owing to the war, and reliability in such engines became established. In the demand for motor-ships subsequent to the war the shipowners (who are not the shipbuilders) naturally required the installation of engines of proved reliability and British firms in their own interests were compelled to secure licences to build such engines as the Burmeister & Wain, Sulzer, Werkspoor, &c. Their only alternative would have been to spend large sums in developing, at an unfavourable time, engines of their own design (a very slow matter in virtue of a lack of knowledge and experience) and still be faced with the uncertainty of securing orders for such engines in face of the shipowner's natural demand for established designs. Moreover, it would be found that vital and necessary features would be protected by patents which would involve them in an outlay on royalties. Their decision to take out foreign licences was therefore governed by their primary interests and for this they cannot be blamed. British engineering practice, however, has assisted to a marked extent in establishing the reliability of such engines and in many cases firms are now free to modify the designs to increase efficiency and reliability without reference to the original firm whose type of engine they have taken up. Some new British engines are being developed and when exhaustive tests have demonstrated their suitability it is possible that they may be extensively fitted. The smaller Diesel engines constructed by certain British firms for dynamo and auxiliary work enjoy a good reputation and are the equal of or superior to foreign designs, but of the distinctly British large engines the Doxford is the only one at present for which there is any great demand. The Still engine is a speciality of this country but as remarked previously it is not extensively employed.

In conclusion it may be desirable to emphasize that the arguments put forward in this article have been dealt with as simply as possible. Each phase of the subject is replete with complexity and hence figures have been avoided where these may lead to false conceptions. Where figures have been quoted they must still be used with caution and not taken as necessarily absolutely correct, but the conclusions deduced may safely be taken as a basis for forming fairly definite opinions on the present state of development, and clearing up important misconceptions.