MARINE ENGINE DESIGN AS AFFECTED BY LIFEBOAT SERVICE CONDITIONS.

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THOSE who were associated with the pioneer work in connection with the racing marine engine will, the author feels sure, accept as an apology for the introduction of such a subject to this Institution the fact that those early marine engines had a very beneficial effect upon the design of the racing car engine—the precursor of our present touring and commercial engine. Again, an engine which did well on the road, was often found quite inadequate when called upon to run under marine conditions at full power and speed for several hours on end; steps had to be taken to eliminate this defect, and this process of elimination eventually produced the aero engine, which, to complete the cycle, has found its place in the racing boat with an excellent showing.

The marine engine has always been, and is still, the Cinderella of the motor industry, and the author wishes to state, with due regard to the significance of the statement, that there is no British marine petrol engine upon the market even to-day, and by a marine engine, he means one that embodies in its design and construction the main essentials of the type. If this is the case to-day, the state of affairs can be imagined when the Lifeboat Institution in 1904 decided to install an internal combustion engine in one of its lifeboats as an experiment. An English engine was chosen, but it proved so unreliable that it was soon discarded. The engine, which was an effort on the part of a small firm, was a misconception from the very start of its design, and its failure nearly postponed the construction of motor lifeboats until such time as an actual marine engine was really in being. The Committee probably saw, however, that the work was pioneering and carried on with it, and a well tried and well known American make was then chosen. This, too, failed, no doubt owing to the weak point of these engines—their inefficient carburettors.

The next step taken was to invite some of the makers of petrol engines to submit trial engines, and this invitation was responded to by two well-known firms, and two less well-known firms, the latter being Mr. Blake, of Kew Gardens, and Messrs. Tylors. The engine from one of the better known firms was a consistent source of trouble and was soon discarded, but the product of the

other firm is still in existence and is giving excellent service, though it should be added that very considerable modifications have been made to the engine and the equipment supplied has been largely replaced. As indicating how far the design of these engines was from fulfilling marine requirements, it may be mentioned that the circulating pump had a steel spindle, and a gland which allowed the leak to get into the crankcase, and which was in such a position that if it needed examination the whole engine had to be removed from the boat, although it had been designed for the job from hull drawings that were supplied.

The Blake engine, installed in the Walton-on-Naze boat in 1906, is still giving good service, though the fitting of a modern carburettor effected a considerable improvement: we have had practically no trouble with the engine itself, except that in 1914 the crankshaft broke through a hidden flaw, but the boat has had three reversing gears and badly wants another.

At this time Messrs. J. Tylor and Sons were making a serious bid for the motor trade, and they really did try to comply with the specified requirements of the Lifeboat Institution; two of their 1908 engines are still giving good service. These engines had four T-headed cylinders, $6\frac{1}{2}$ in. bore by $7\frac{3}{4}$ in. stroke, cast separately, giving a little over 70 h.p. at 700 revs. per minute, the valves being operated by two camshafts, and the type remained as the standard for lifeboat engines till the spring of 1921, when the last of them was delivered. They were fine looking jobs, but the crankshaft was too weak. The crankcases were made of gun-metal, which the author has found to be somewhat plastic, and the separate-cylinder construction to his mind is weak, especially when gun-metal is employed. They were also difficult to build, since it was impossible to jig them properly owing to the small quantities, and the hand fitting required was abnormal, while the oil pump was inaccessible, the plug design was very defective, and they were far from quiet. The running faults, however, were very few; the compression was too high, which caused pinking till a $\frac{3}{8}$ in. by-pass pipe was fitted from the exhaust manifold to the induction pipe, but the great trouble was the rapid depreciation of the bearings, in fact practically every engine required a new set of bearings every year or, say, after one hundred hours' running. This was found to be due to the white metal not properly adhering to the shell, and to sand working out of the crankcase casting. The importance of having perfect adhesion of the white metal is now realized, and the inside of the crankcase is painted with a special enamel, and since 1915 there has not been the equivalent of a full set of bearings supplied throughout the whole fleet.

Since then in fact, minor electrical faults, leaks and short-circuits through the salt water and failure of cocks and fittings have caused the bulk of the few stoppages and mishaps that have been experienced, and the only real mechanical weaknesses that

have existed and in fact still do exist, are the thrust bearing in the reversing gear. With one or two exceptions, the boats belonging to the Institution are fitted with reversing gears having the usual multiple-collar thrust, and in practically every case the working heat of this bearing approaches 175°F . In such circumstances it requires very little excuse for the white metal to run, and in some bad cases a "Distance Thermometer" has been fitted as a precautionary measure. The reversing gears are undoubtedly the weakest link in the chain from a mechanical point of view, though by the very nature of things, this weakness does not often cause stoppage. Nearly every gear on the market has been tried, and the most satisfactory is a gear which is very heavy and cumbersome, which contains many exposed working parts, and which embodies a considerable amount of "Millwright" practice.

It will, of course, be understood that the requirements of the Lifeboat Institution in connection with reversing gears are rather severe, but the author does not consider that they are unreasonably so. Among the tests applied, the boats are run over the measured mile astern, and it is required that the gear shall be put from ahead to astern in not more than one revolution of the control wheel. Further, it must not be possible to force the wheel into either position and leave it to continually apply end pressure on bearings, a point of failure on many of the early gears. In practice it is found that a boat weighing 17 tons and travelling through the water at 8 knots, when propelled by an 80 h.p. engine, can be brought to rest in eleven seconds from the bell, a feature of the greatest value in actual service.

Very early in the application of the internal combustion engine to lifeboats it was found that the commercial article, as far as equipment was concerned, was utterly inadequate for the work of the Lifeboat Service, and detail by detail the special equipment necessary has been designed. The best of petrol cocks were not substantial enough, and were fitted with steel pegs, springs or screws, while no attention was paid to the threads, and so with nearly every other item. Even the semi-rotary pumps for pumping lubricating oil from the store tank had to be specially designed and made for the Institution.

Pressure gauges, electrical meters, lamp holders, etc. are standard articles, but as such they are quite inadequate for the requirements of the lifeboat service, and as a pressure gauge that is rust-proof and watertight cannot be found, the modern practice is to enclose these meters in a frame with a glass front, and to keep this frame dry with a capsule of carbide. As the standard switches and holders are only on the lighting circuit it does not matter much, but all switches on the ignition circuit are to the Institution's design, incorporating the laminated bridge switch, though the latest practice is a barrel controller.

It may be of interest to outline the installation of machinery in one of the later types of boats fitted with a Tylor 70 h.p. engine

and built for the Institution by the Weyburn Engineering Co., Ltd. This boat, examples of which are to be found at Campbelltown, Beaumaris, Blyth, Kingstown, Peterhead, etc., is one of the largest class, and is 45 ft. long by 12 ft. 6 in. beam, and, as before mentioned, displaces about 17 tons. The engine, which has cylinders $6\frac{1}{2}$ in. dia. by $7\frac{3}{4}$ in. stroke, gives about 70 b.h.p. at the usual speed of 725 revs. per minute, and it will be readily understood that the boats are overpowered, or as it can be better expressed, they have an ample margin of power; this is, however, necessary in order to enable them to cope with special circumstances that arise, and to be manœuvred readily.

The motor compartment, which is made just large enough to house the engine and reversing gear, silencer and various small fittings, is bulkheaded off from the rest of the boat, and is lined with copper; the bulkheads, which are from $1\frac{1}{2}$ in. to 2 in. thick, run right up to the deck and then are continued in the form of coamings upon which is mounted the motor hood, a very substantial pair of flaps with watertight seals and clamping screws.

FIG. 2.—Stern tube.

Two three-inch bearers are worked in, right fore and aft, and the engine and reversing gear are secured to these by bronze set screws and locating blocks. Brass pads are secured to the angle irons which are attached to the bearers, and these pads are machined and filed to provide adjustment in the alinement.

It will be readily agreed that the correct method is to incorporate the reversing gear with the engine, but unfortunately, in these installations they are separate, and as it would be out of the question to assume permanent alinement, a universal joint is fitted between the engine and the gear. This joint consists of a diaphragm of fabric and rubber moulded complete with holes in the centre which register with those in the coupling of the reversing gear, and spigoted into the face of the flywheel and secured by a clamping ring. In order to get alinement between the engine and the gear, a jig in the form of a distance-piece is used, which is bolted to the engine crankshaft and the reversing gear coupling is lined up to it.

The stern tube (Fig. 1, Plate I, and Fig. 2) is a special design of

the Institution, and has an interesting feature inasmuch as the part that is bolted to the stern post is provided with a sleeve which envelops the boss of the propeller. This serves the purpose of preventing cordage from being picked up and wound round the shaft between the propeller and the stern tube, and also provides a means of transmitting any lateral strain from the propeller direct to the stern post. As the after bush is bolted to a cast bronze aperture-frame, the whole boat could be jacked up by the propeller without straining the shaft.

To ensure alinement of the stern-tube bearings, the tube itself, which is of substantial construction, is counter-bored at each end to take two bushes at the after end and one at the forward end, these bushes being standardised gun-metal shells lined with white-metal. The protecting sleeve also acts as a cover to the after stuffing-box which is not adjustable, and an identical stuffing-box is provided at the forward end. The tube screws into the after casting and is nutted up to another casting at the forward

FIG. 3.—Two-way petrol cock.

end through which it passes, so that it is rigidly held, but the space in the deadwood is filled up with thick white lead which gives to the expansion of the wood. A small header tank is connected to the tube by one branch of a tee-connection, the other branch going to the hand pump, and thus the tube is kept full of oil at a pressure above that of the sea. The shaft is of manganese bronze, and the tapers and keyways are made to gauge, while the couplings are drilled to jig so that everything will interchange.

The fuel supply is in duplicate, from two cylindrical 40-gallon copper tanks, each situate in a separate hold. Two distribution cocks are provided which control both the petrol and the pressure air, and from these a pipe passes to a two-way cock, Fig. 3, situated at the bottom of a small gravity tank, the mechanism for actuating this cock being situated on the Instrument Board, where, by the simple pulling out of a handle, the main supply is cut off and the gravity tank placed in operation.

The tanks are made of 16 gauge half-hard copper with folded or hook seams sweated up, a method of construction which is more sound than brazed joints, as the hook seam is as strong as the material itself and is not subjected to the annealing action of brazing; the solder is only required to make a petrol-tight joint. To prevent corrosion, the tank is tinned throughout before being made up; it is also stoved on the outside after completion.

All tanks are tested at the makers' works by filling them with air up to a pressure of 30 lb. per sq. in. and then submerging them in water, and again after delivery they are partially filled with paraffin and then steam is let into them from a boiler till the pressure reaches 20 lb., when they are turned about so that the paraffin may come into contact with every joint. As all vulnerable places have previously been painted with flat black the slightest leak manifests itself, and tanks which have been quite sound under the air test, often show small leaks under the steam test. A saddle casting carries all the connections—the filling opening, the level gauge, the petrol delivery pipe and the air pipe—and is nutted and soldered to the tank.

Air pressure is supplied to the tanks by means of a mechanical pump on the engine, or a hand pump forming part of the installation; by means of the petrol control the air pressure can be kept in both tanks, while the petrol is being used from one, the other tank thus being left ready for immediate use if required.

The petrol controls (Fig. 4) are multiple-way cocks situated inside the engine compartment with the actuating handle and a marked dial plate on the outside. As these cocks are somewhat large in diameter, and have to be spot tight, they are difficult to produce, but by reaming the bore and grinding the plug and afterwards lapping it in with rouge, it has been found possible to make a good job of them.

All the connections used in these installations are specially made to the design of the Institution's engineers, and are somewhat heavier than the usual commercial connections. In practically every case a pipe is connected to a fitting by providing the fitting with a female socket tapped to the particular size of pipe thread, into which a male connection is screwed, while the pipe is brazed into the nipple, the latter being red phosphor bronze in the small sizes, which can be produced in a capstan lathe, and cast brazing metal in the larger sizes.

The water circulation is also duplicated, a closed fresh water running circuit and a stand-by salt water circuit; in the running circuit the amount of water passing from the pump to the engine is under the control of a by-pass which turns some of the water into the exhaust jacket should the engine be found to be too cool. From the cylinders the water passes to the exhaust jacket, and then through a four-way cock to one of the two coolers which are situated in separate wells, then to the other cooler, and back to the pump via a second four-way cock. A small header

tank is connected by a Tee-piece to the circuit to make good any loss, though this is very small indeed. The object of the four-way cocks is to enable the fresh water circuit to be cut out and a connection made with the sea at any time. There are several reasons for the use of fresh water and an enclosed circuit; for instance, sea water leads to corrosion and to heavy deposits of sand in the jackets when the boat is working amongst the sands

FIG. 4.—Petrol controls.

in bad weather; the author has known the exhaust pipe jacket and the cylinder jackets to become entirely filled with sand and slime in one trip. Again, sea water means a sea inlet somewhere, and this may readily become choked, though very definite precautions are taken by the Lifeboat Institution to guard against this, even in the stand-by sea-water circuit.

The only points of departure from the usual practice with regard to the lubrication are the oil cooler, which is situated in the

relieving well, that is to say, right in the sea, delivering the oil to the engine at about 80° F., and a hand pump and multiple control cock which allow oil to be pumped from the store tank direct into the forced-lubrication feed pipe of the engine, through suitable non-return valves, or to the stern tube, or to any other point that may require oil. By this means the engine is primed with lubricating oil before it is started, and should the pump give out, oil is pumped into the crankcase, via the bearings, till the engine runs on splash. This control and the pump are situated on the Instrument Board.

The exhaust pipes and the manifold are jacketed, the former being made of copper, and all flanges are drilled to jig. The silencer consists of two tubes with distance-rings at each end giving a water space of half an inch, and there are the usual saddle connections brazed to the outer tube. The tubes and rings are brazed up and then faced in the lathe, after which they are tapped to a jig, and the dry brass end-plates are secured by studs with asbestos packing. There are therefore no water-joints to make at the ends, and the silencers can readily be taken down for cleaning. A number of "Claire" baffle cups are inserted in the silencer proper, but it is advisable that the exhaust should be just audible in order that a "miss" may be picked up.

The electrical arrangements have always been a great source of anxiety, and the wiring was always giving trouble till a special wire was made for the Institution consisting of a stranded conductor moulded into an ebonite dielectric, $\frac{3}{8}$ in. in diameter. This wire, which is purchased in short lengths, is heated and bent to shape, and is cleated to the walls of the motor compartment with brass cleats. As neither petrol, oil or moisture affect the ebonite, no trouble is experienced with these wires, but it must be understood that all floating ends consist of the ordinary flexible cable jointed to the ebonite wire. The joints in the latter are made by sliding a vulcanite fibre sleeve over one wire, joining up and soldering the conductors, filling up the space with Chatterton's Compound, and then sliding on the sleeve. This makes a perfectly sound and mechanical joint.

In some cases a low-tension magneto is used, while in others a lighting dynamo converted to a plain shunt-wound machine is employed, both being gear-driven from the engine, and the current is taken to a special coil-box provided with a multiple switch. A four-cell accumulator is employed, the tops of the cells being covered with an ebonite plate bedded down on thick grease as a precaution against fire, and the leads from this battery are also taken to the coil-box.

A C-shaped inductive coil is employed, and it is interesting to recall that practically no information could be obtained to help in the design of these coils, which was arrived at purely by experiment. The width of the air gap was found to have a very important effect on the magnitude of the spark, while the thickness

of the winding was, of course, the governing factor as regards the speed of the coil. However, with some of the present coils, when an eight-volt battery is used, a spark of over one inch in length can be obtained. Where the low-tension magneto is in use, a dynamo is driven by belt from the engine, and in this case an automatic cut-out is used.

By this arrangement the engine is started on the battery acting through the inductive coil and switched on to the magneto, or where

FIG. 5.—Capsizing switch.

Mercury is emptied from chamber and through the two passages shown, so breaking contact, but can only return slowly past the retarding valves.

the dynamo is geared to the engine, the current passes through the coil in both cases. There is a "capsizing switch," Fig. 5, placed in the circuit to the bus-bar in the case of self-righting boats, and this breaks the circuit when the boat is capsized and makes it again when she rights herself. In order to avoid the possibility of the engine starting away again and leaving the crew in the water, the circuit is, however, not restored till after the lapse of about 30 seconds.

The throttle gear is so arranged that when the reversing gear is

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in neutral, the throttle is automatically closed and the engine runs on the by-pass, and then when the gear is placed in either ahead or astern position, the throttle opens to the predetermined amount as set by the hand throttle-lever.

The starting gear consists of a handle with a chain shaft and chain wheel in a watertight gun-metal box, in which are also located two small handles for working the starting dog on the engine and the half-compression and retarding gear so as to simplify the starting as much as possible. It is nevertheless still somewhat of an undertaking to swing an engine of this size on a cold morning.

There is a circuit arranged for in the coil-box which deals with the electric lighting, and a special side-light, together with a disappearing head-light, had to be designed for use in these boats, since the commercial article was found quite inadequate for the work.

Practically all the controls, and all gauges, etc., are carried to what is termed the "Instrument Board," which forms the after end of the engine hood, so that there is very little need for lifting the hood. It will be understood that if the weather is at all bad, it is impossible even to open the hood to ascertain the nature of a fault, much less to do any work. The nature of the service upon which these boats are employed renders it absolutely imperative that not only must all controls be brought to the outside, but that the engine *must not stop*.

The engine is supplied with air direct from the hold through two valves which close should a few inches of water enter the hold. Even if the hold is quite full, these valves prevent water from getting into the engine room. The hold is supplied from the after end-box, which is in turn supplied through a ball valve, and this closes if the boat capsizes. Should the hold valves close, there is another source of supply via a pipe leading direct from the engine compartment to the end-box where another valve normally closes this entry, but lifts under the slightest pressure-difference. The result is that the boat could be entirely submerged for a considerable number of seconds without the engine stopping, and it would be almost impossible to get water into the engine room in this way, while the drawing of air from the hold keeps away rot and prevents the accumulation of vapour. It may be added that these boats are steamed over the mile, and generally manoeuvred under conditions which are akin to being "stove in," and all self-righting boats are put through the capsizing tests when full of water.

The testing of this machinery is fairly exhaustive, although it is in no way "academic." The design of the engine is assumed to be correct, or at least completed, and the test therefore has for its objective the elimination of mechanical faults throughout the installation. The engine is run on the test bed till everything

appears satisfactory, and the consumption and brake horse-power are taken, the power being absorbed and measured by a Froude Dynamometer. After everything is finished, a six-hour full-power test is made, and if there is no fault the engine is taken down and examined and the bearings are touched up and any necessary work carried out. It is then painted the final coat on the outside and re-assembled. In order to make sure that nothing has been disarranged, the engine is again run and finally passed for issue to the Building Yard. When the installation is completed, every circuit is tested as far as possible, and the engine is then run for a few hours at light load while the boat is at moorings. The preliminary trials simply consist of running the boat to some convenient crane where what are termed "the Harbour Trials" are carried out.

Although these trials are in no way connected with the machinery except as regards the capsizing switch, it may be of interest to outline the details. The boats are designed to carry a certain number of crew and passengers, and an equivalent weight in what are termed "Dead Men" is lashed to the benches and thwarts and remains there for the trials. The draught of water is taken, and then further weights are added till the deck is awash, till the gunwale is just under water with all the extra weight on one side, and so on. Then, if she is a self-righting boat, she is parbuckled with a long sling, and the crane heels the boat over with the engine running. At about 60 degrees the capsizing switch comes into action and the engine stops. When she is bottom-upwards efforts are made to get her to balance, of course with no desire that success should crown these efforts, and finally she swings over with a rush, scoops herself full of water, and the stop-watch records the time taken to get rid of this water through the relieving valves. The engineers jump aboard immediately and the engine is started up, generally without any trouble.

The boat is also capsized with the hold as full of water as the air cases with which it is packed will allow. Then the masts are stepped, the sails set and sheeted home, and the boat is again capsized as far as the masts allow, and on slipping the crane she rights herself under these conditions.

When the Harbour Trials are finished, she immediately goes to the speed trials. A few runs are made at half-power, a few more at cruising speed, and then six runs are carried out over the measured mile at full power, records of the speed, petrol consumption, revolutions, etc., being taken. It is interesting to note that in the records of five boats identical in design, which have been tested of late, the speed varies from 8 knots to 8.2 knots.

Any small adjustments are then made, and the boat is finished off, the final coat of paint applied, the whole of the gear placed on board, and the Station crew warned. When everything is ready, what is termed the six-hour run is made, when, after, say,

an hour's observation run, the hatches are screwed down, and the boat is run for six hours at full speed. At the end of this run if everything is correct, the crew are sent for and she proceeds to her Station under her own power.

Some of these delivery trips are excellent tests in themselves. For instance, to take a boat that can only do, say, 100 miles a day, up to Wick from the Solent means several days' running, for suitable ports for stopping at and picking up fuel have to be chosen, and by the time she does arrive at her destination, any mechanical weaknesses which there may be have generally developed. In many cases these weaknesses are quite trivial and yet fatal to the service on which the boat is engaged, as mention of a few which have actually occurred will demonstrate. A taper pin worked loose in the throttle gear, a petrol cock union gave out owing to vibration and a water joint blew out and flooded the engine room—each trifle in itself was sufficient to completely disable the motor power owing to the impossibility of getting at anything with the sea that was running. Yet we have to obtain reliability with engines that are nothing very out-of-the-way in themselves; in fact we have obtained excellent service from ordinary standard commercial vehicle engines by simply paying attention to details. Accordingly, we design the petrol cocks ourselves and make them substantial, to gauge and out of the best possible material; we have the small amount of insertion used by the Institution specially made by going to a good firm and telling them to select the best possible material and let us have the reference number, and so on. In consequence of the great care taken, we have not had many failures—the human element lets us down sometimes, but failures are getting less and less as time goes on. We want our boats to last twenty-five years and never to fail, and that is why a petrol cock or a switch bought on the market is not suitable for our service.

In order to facilitate the carrying out of renewals, the Institution has tried to standardise as much as possible. British Standard Whitworth, Fine and Pipe threads are, of course, insisted upon, and a very full set of gauges is used for checking these threads. The small fittings are drilled to jig, especially the base plates of those which have to be screwed to bulkheads, as this allows for the return of a faulty fitting, and the installation of a new one without trouble. Flanges for pipes are drilled to jig, but a special standard had to be made as there was nothing in existence as a guide, and shaft couplings are bored and slotted to gauge and drilled to jig. All propellers and tail shafts are made to gauge. Here, again, the Institution had to make its own standard. In fact, wherever there is anything to be gained by so doing, a jig or gauge is used, and wherever the British Engineering Standards Association have issued a specification it is used, though it is very disappointing to note the ignorance and apathy shown towards this question of standardisation by the

ordinary engineering firms, especially large firms with an old-established business and a big reputation.

PART II.

After seventeen years of vain endeavour to obtain a marine engine to meet their needs, years of compromise and of adaptation, the Committee of Management of the Institution were forced to the decision that they must themselves try to produce an engine which should be suitable for the special work and arduous conditions of the Lifeboat Service. A Specification of the requirements was accordingly drawn up, and eventually the design and construction of an engine were entrusted to a well-known firm. The design was to be based upon the Specification issued, and this Specification was to be followed up with further detail as the design progressed.

The following extracts from the Specification will indicate what the Institution had in mind. How these ideas have been worked out will be illustrated more or less in detail by reference to the six-cylinder unit that has been produced.

"The engine is to have six cylinders having a bore of $5\frac{1}{2}$ in. and a stroke of 7 in.

"The datum revolutions to be 800 per minute, at which speed the engine is to develop 76 b.h.p.

"The engine is to be monobloc with detachable head, overhead valves, self-contained with reversing gear, thrust and starter.

"The body, of cast iron, to be a box water-jacket integral with the crankcase and reversing-gear facings, and to contain both exhaust and inlet manifolds.

"The cylinders to consist of cast-iron sleeves forced into the body.

"The head to be a single iron casting containing the valves, camshaft, igniters, etc., the valves to be under the camshaft with large guides and flat heads.

"The crankshaft to be three inches in diameter with four bearings.

"Lubrication to be forced throughout, duplex filters being attached to the engine, all outgoing shafts and controls to be provided with stuffing boxes and oil seals.

"The reversing gear to be contained in a housing bolted to the crankcase and to consist of a multiple-plate clutch running in oil, bevel differentials and a balanced brake, all bearings in the reversing gear to be under forced lubrication.

"Dual ignition to be fitted, consisting of low-tension and high-tension with separate high-tension coils.

"The ignition to be actuated by a separate ignition-shaft driven by the camshaft and adjustable as to phase for timing purposes.

"The cylinder-head to be protected by an oil- and water-tight

cover and the whole engine to be arranged in such a manner that it is water-tight and damp-proof.

"The carburettor to be water-tight and the throttle to be governed by hand, by the reversing gear, and by the governor."

Two things must be realised in connection with these boats: examination or adjustment of the engine is quite impossible under service conditions, and moreover, the engine is in a position entirely below the deck of the boat, as shown in Fig. 6.

It was realised that if the crankshaft, bottom ends and main bearings were a good, substantial job, they would require very little attention, and therefore it was assumed that if any overhaul

FIG. 6.—Showing position of engine in a lifeboat.

of these parts were required, the engine had better be lifted out of the boat. All delicate apparatus has therefore been mounted on the detachable head (Fig. 7, Plate I, and Figs. 8 and 8A), and the head is arranged in such a manner that it can be removed by breaking only the one main joint and without touching the water, exhaust, oil or petrol connections. When it is removed the whole of the valve gear, ignition arrangements, etc., can be cleaned and adjusted, and actually operated by hand before the head is replaced, so that the work can be carried out under reasonable conditions. The water is passed from the main jacket to the head through tubes and spigots with rubber rings, in such a manner that it does not come in contact with the main joint itself.

FIG. 8.

FIG. 8A.

The camshaft is driven by a pair of bevels from a vertical shaft, these bevels being held in the head and the connection being made by a "one-way" semi-universal coupling arranged to lift out with the head. The ignition-shaft is driven from the camshaft by a pair of helical gears, Fig. 9, that on the ignition-shaft being mounted on splines and being capable of being moved fore and aft by the timing gear, thus adjusting the ignition timing for both the high-tension and the low-tension ignition. In order to prevent injury from a reversal, there is a spring dog-drive between the splined sleeve and the shaft, and this allows a pure snail-cam to be used for the low-tension ignition, and thus a very hot spark is obtained at starting.

The body of the engine (Fig. 10, Plate II) is carried right down to form the sump, a flat plate of steel being bolted along the bottom to make it oil-tight. This construction provides a very rigid engine, a most necessary feature in marine practice till we are bold enough to employ three-point suspension.

The crankshaft may appear to be excessive in diameter for a slow-running engine, but its size is justified by the increased im-

FIG. 9.—Ignition-shaft gears.

munity from bearing trouble and the damping out of vibration, as has already been proved by experience. At the same time it introduces a minor difficulty in arranging for the connecting-rods to be drawn out through the cylinders.

The inspection doors on the crankcase allow of any bearing being taken down and replaced, and are amply large enough for general inspection purposes. They also allow of the removal of pistons and connecting-rods, the whole number of which can be withdrawn easily within the hour.

For constructional purposes the exhaust manifold is semi-enclosed in the main casting, the outer half of the water jacket being attached separately, and for the purpose of even distribution there is a bridge-piece on the inlet manifolds.

The flywheel, which is enclosed in a housing at the forward end of the engine, is very small though quite adequate for the purpose; the crank centres are marked on the periphery, and these can be viewed through a door provided for the purpose.

The after end of the shaft is splined, and on these splines are mounted the main transmission pinion and a helical gear for

operating the bilge and circulating pump spindle, also the oil-pump drive. Attached to this helical gear wheel is the bevel for driving the vertical shaft, and a further large-diameter helical wheel which is operated by the starting gear. At the forward end is arranged another bevel wheel driving a vertical shaft which carries the governor and drives the dynamo, both of these elements being entirely enclosed.

Both the bilge and the circulating pumps, Fig. 11, are of the turbine type, and as the circulating system is somewhat of a departure from the usual a detailed description may be of interest. The pump suction S is taken direct from the sea, or from a cooler, and the water is delivered via the pipe A to an inlet connection I at the centre of the jacket, and thence by a number of holes direct into the head. From the top of the head two collector down-pipes lead it through the joint, into the jacket of the exhaust manifold C whence it is discharged into a thermostatic-valve box E. The thermostatic element L when the engine has just been started up with everything cold, normally closes the delivery valve D and directs the water to the suction of the pump with the exception of a small quantity which is purposely allowed to escape. The water is therefore at first simply circulated round the engine at the full capacity of the pump till the temperature rises to a pre-arranged point, 160° F. in this case, when the thermostat comes into operation, slightly opens the delivery valve D to the sea and closes a like amount the by-pass valve G. This continues till, when the water has attained a temperature of 180° F., the by-pass is quite closed and the whole of the water is drawn from, and returned to, the sea. If, therefore, the engine is started on light load, the temperature quickly rises to the working point where it remains, no matter how much the load is increased, and no matter what the temperature of the cooling water may be. This, in the author's opinion, is a vital point in all marine engines of any size.

The pump drive spindle H is driven by the spiral gear J from a larger spiral K fixed on the crankshaft; at the two extremities of this spindle are tongued the two pump spindles M and N. The drive spindle and both pump spindles are supplied with forced lubrication, and great care has been taken to prevent leakage of oil or water. The bilge pump automatically comes into operation as soon as any quantity of water enters the engine room, the pump suction being arranged as close to the bottom of the boat as possible, while a very small quantity of water would drown the pump. The pump units are readily detachable from the engine without in any way disturbing the forced lubrication pipe O or the drive spindle.

The oil-pump and its gears are mounted on a door and are bodily removed with the door; the pump is of the wheel type and is of ample capacity, and is fitted with a safety valve set to blow at 30 lb. per sq. in. From the pump, the oil passes to the duplex

FIG. 11.—Circulating and bilge pumps showing connections to thermostatic valve.

filter (Fig. 12), either half of which can be cleaned while the other is in service, and thence to the cooler. On leaving the cooler, the oil is taken to a fitting provided with a pocket for a thermometer, and a connection for the hand pump. This fitting delivers the oil to the internal circuit, Fig. 13, which consists of a pipe mounted on the bearing caps, which feeds the crankshaft from each bearing and has a branch to the pump shafts, and another branch at the fore

FIG. 12.—Duplex filter.

end, which runs up to the head and delivers oil to a distribution pipe carried upon the camshaft bearings; this pipe delivers oil to those bearings and is also drilled to take split pins over each cam, an arrangement which provides all the oil that is necessary without flooding the valve stems; there is also an internal branch to the ignition-shaft bearings. At the further end of this pipe there are a relief valve discharging into the bevel gears and drains allowing the oil to return to the crankcase, one being by way of

the vertical shaft. Close to the relief valve is a connection to a pressure gauge, which enables the pressure at the very end of the system to be ascertained. There is a strum-box in the sump at the end of the suction pipe, and where the pipe comes outside the crankcase a ball-type foot-valve is arranged which prevents the draining of the pipes and positively primes the pump.

A small fitting carries a dial-type level-indicator, a plain dipper rod, and a spring drain-valve. The capacity of the sump is about eight gallons and this quantity of oil should last for some time.

The ignition consists of a low-tension and a high-tension system, the former being considered the primary system, while the latter is considered a stand-by. In the case of the former, the current is led from an eight-volt accumulator to an ebonite insulated conducting plug which leads the current to the space under the hood or head cover, and to a bus-bar running right along the cylinder head. From this bus-bar the current is led through switches to the mica-insulated electrode on the igniter, which also carries the high-tension plug. The igniter has a direct metal-to-metal seating in a pocket formed in the side of the head-jacket and protected by a jointed plate, and a brass bush is let into the top of the head and drilled to carry the needle operating the movable electrode, and the low-tension and high-tension wires. The movable electrode is held in contact by a spring, and contact is broken by a bell-crank spring hammer operated by a snail-cam on the ignition-shaft. The current passes through an inductive coil, the mean of the current required to operate the six igniters at normal speed being two amperes.

The high-tension system consists of another bus-bar carrying the battery current with leads to six separate Delco coils which are enclosed in damp-proof Bakerite cases, and from each of which a high-tension lead of ebonite-covered wire is carried through the brass bush already mentioned to the high-tension plug in the igniter, Fig. 14, and also a low-tension lead to a low-tension distributor and timing contact. This distributor is driven by worm gears from the ignition-shaft, and is adjustable as to phase with that shaft, and therefore with the low-tension ignition and the timing lever which is carried on the Instrument Board controls both ignitions. The single-spark system was adopted in order to avoid complications, and so far it appears quite satisfactory, though it is obvious that if a trembler had been introduced in the primary circuit of the high-tension system even better starting conditions would have been obtained.

This whole arrangement eliminates the danger of any terminal or live conductor being exposed to the external atmosphere and thereby to the effect of damp or spray, and as far as the ignition is concerned, the engine is not only spray-proof but is submersible.

At the forward end of the engine there is a pocket formed to carry the governor (Fig. 15), which consists of four one-inch bearing balls which can move outwards up an inclined plane to lift the

governor collar, so eliminating springs, and this is mounted on a spindle driven by bevel gears from the crankshaft, and above the governor is a flexible coupling which drives the dynamo in a

REFERENCES ON FIG. 13.

- A. Oil feed to camshaft bearings at front of engine.
 - B. Governor control, rod piece and sleeve pressure lubricated. Governor casing filled with excess oil.
 - C. Camshaft gear and ignition mechanism, lubricated by oil fog. Excess oil drains to rear oil wells and is utilised for vertical drive shaft lubrication.
 - D. Piston and gudgeon-pin bearings lubricated by splash.
 - E. Radiator thermometer connection. High temperature.
 - F. Terminal connection to oil-pressure gauge.
 - G. Starting engine lubricated by hand pump.
 - H. Starting mechanism, self-contained lubrication.
 - J. Oil baffle-plate.
 - K. Oil strum-box.
 - L. To water pumps, drive shaft bearing.
 - M. Weir to collect sludge resulting from application of reversing gear brakes.
 - N. Reversing gear drum, filled with oil, fed through spigot bearing, lubricating gear teeth, bushes and end plate bearings.
 - O. Thrust bearing lubricated by "trough" fed by excess oil through bearing bush.
 - P. Drain for reversing gear housing.
 - Q. Bearing brackets drilled for pressure service to ignition shaft bearings.
 - R. Connection to pressure gauge, see elevation.
 - S. Oil filler and strainer.
 - T. Detail view of oil drain valve.
 - U. Connection to oil cooler.
 - V. Duplex oil filter.
 - W. Circulating and bilge pump glands and spindles. Pressure-sealed and lubricated.
 - X. Oil-pump.
 - Y. Connection from oil cooler.
 - Z. Oil suction foot-valve box.
 - A₁. Handle for oil drain.
 - B₁. Oil level indicator, blade type.
 - C₁. Oil level indicator, dial type.
 - D₁. Radiator thermometer connection, low temperature.
 - E₁. Connection to high-pressure oil gauge.
 - F₁. Connection from oil cooler to main oil pipe.
 - G₁. To oil cooler.
 - H₁. Relief oil on to timing gears.
 - J₁. Terminal connection to pressure gauge.
 - K₁. Detail plan of oil pump, showing safety valve. Valve operates at 60 lb. per sq. in.
 - L₁. Return to crankcase.
-

vertical position. At normal speed this dynamo will charge the cells at about four amperes, and it is controlled by a B.L.I.C. cut-out and a specially designed hand switch.

The carburation is a departure from the usual, inasmuch as the

carburettors and float chambers are quite watertight and are a combination of the principles of the Claudel and several other types. The jet is shrouded somewhat on the lines of the Solex, and submerged, but instead of the shroud being fed with atmospheric air it is supplied with exhaust products through a duct

FIG. 14.—Low-tension igniter.

which leads through the throttle spindle and is controlled by a regulating screw, as shown in Fig. 16. This was adopted as the result of previous experience with a pipe $\frac{3}{8}$ in. dia. from the exhaust manifold direct into the induction pipe at the top of the "Y," where the hot inert gas mixed with the petrol spray, thoroughly

vaporised it and prevented freezing up. A further supply of exhaust gas is admitted into the manifold above the throttle, and when the engine is running slow an increased quantity passes to the induction pipe, resulting in an increase of temperature which greatly facilitates acceleration. Two carburettors are used, the manifolds being connected by a balance pipe, and the throttle controls are coupled together and carried to a throttle-gear box which is quite complicated, though not unnecessarily so.

The hand-throttle is worked from the Instrument Board, and is

FIG. 15.—Governor, showing balls and inclined plane.

in reality a maximum stop. Another lever, also worked from the Instrument Board by a small hand-wheel, forms the minimum stop, while the throttle-lever proper is pushed into the closed position or allowed to open by the automatic lever actuated by a cam on the reversing-gear control spindle. Thus, when the reversing gear is placed in the neutral position, the automatic lever closes the throttle entirely and leaves the engine running on the pilot, while the action of going into the "ahead" or "astern" position opens the throttle. As, however, it is necessary to limit the amount of opening, the hand-throttle determines the extent

to which the automatic lever shall move the actual throttle on the carburettor in order that the gear may be manoeuvred ahead and astern with either just a little throttle opening or opened out to the utmost.

As in starting up with the reversing gear in "neutral," it may only be necessary to open the throttle slightly, yet, on the other hand, when the engine is operating the capstan gear, quite a considerable amount of opening may be required, the minimum

FIG. 16.—Carburettor, showing exhaust gas connection.

throttle has been introduced, and both these controls are operated by the interposition of a secondary lever connected to the primary lever by means of a stiff coil spring.

All this gear is enclosed in a box attached to the crankcase, and the controls pass through into the inside.

The carburettors are fitted with slow-running jets and also with air baffles for starting up, while the air-intake pipe is carried up quite high and fitted with a cowl. Again, as far as the carburation is concerned, the engine is waterproof and can be sub-

merged to the cowl of the air-intake, for there is a balance pipe from the top of the float chamber into the air pipe, and the air for the slow-running jet is from the same source.

In a motor of this size, where the employment of a standard electrical starting outfit is out of the question, and as compressed air must also be ruled out for Lifeboat Service, the problem of starting is not an easy one. It appeared, therefore, that a small petrol motor was the most suitable alternative, and the cylinder, piston, and connecting-rod of an existing two-stroke engine were

FIG. 17.—Starting motor.

fitted on a body containing the crankshaft and an epicyclic gear which acts as a clutch and reducing gear (Fig. 17 and Fig. 18, Plate II). This unit was mounted on to the top of the reversing-gear housing in such a manner that the pinion at the end of the gear-shaft meshes with a pinion on the starting shaft. The starting shaft is connected by a heavy chain-drive to a countershaft which picks up a hand chain-drive from the Instrument Board through a free-wheel and reversing check. It also carries on a spline a sliding helical pinion which can be moved by hand into engagement with the large helical gear on the crankshaft, the spiral angle of the teeth being such

that it tends to slide them into engagement when power is being transmitted to the main engine. Then by engaging the helical gears and leaving the starting engine epicyclic clutch out of action the main engine can be cranked by the small starting handle at a 8.33—1 reduction. Again, by disengaging the helical gears and putting in the epicyclic clutch the little engine can be started, and when running the clutch is taken out and the helical gears engaged and the clutch put in again, when, with a gear reduction of 33.5—1, the main engine can be turned at about 60 revs. per minute. As soon as the main engine starts, the thrust due to the angularity of the teeth throws the sliding helical pinion out of gear and the starting engine can be switched off. This engine, of which the cylinder is $2\frac{3}{4}$ in. dia. by $2\frac{3}{4}$ in. bore, appears to be just about powerful enough for its work, even on a cold morning, provided that a helping hand is given to turn the first dead-centre.

It may be argued that the engine is not even spray-proof, and that it is therefore the weak link that would negative all the other efforts to combat the evil effects of damp, but as the main engine can be cranked by hand when cold and started up with the aid of the air baffle, this should not be a very serious weakness, particularly as the plug will be protected by one of the Institution's plug covers, which will allow it to function even when submerged, and the starting engine is carried very high up.

One of the weakest parts of a marine engine installation has always been the reversing gear, and as the Institution has suffered from this to a great extent in the past, an effort has been made in the design of the gear incorporated with this engine to eliminate some of the defects and produce an article that will prove in every way satisfactory. Bad clutches are the most fruitful source of trouble, and for this reason a substantial form of plate clutch, progressive in operation and self-locking, has been provided with the object of having ample transmission capacity. The plates, seven in number, $1\frac{3}{8}$ in. thick, alternately of steel and bronze, are forced together by six dogs, which allows the pressure to be evenly distributed, see Figs. 19 and 20.

The epicyclic gears are plain stub-tooth pinions and mesh into the driving and driven pinions in the usual manner, these latter being mounted on the splines at the end of the crankshaft and gear shaft. All gearing throughout the engine and reversing gear follows the usual approved first-class automobile practice as regards material, hardening and grinding; this practice is, indeed, carried out through every detail.

The weakest link of all, as far as the usual reversing gear is concerned, is the brake. The standard practice is to give a flexible band a turn round the drum, anchor it at one end, and apply pressure to the other, with the result that a considerable amount of lateral strain is imposed on the gear and the spigot. An endeavour has been made to eliminate some of this strain by fitting a pair of locomotive brakes like those on some modern cars

(Fig. 20), and certainly, if sweetness of action is any criterion, both clutch and brake should prove to be quite satisfactory.

The thrust is a double ball thrust of standard type, of ample capacity and capable of being readily withdrawn if required.

Another very weak point in reversing gears is the lubrication; if the gear is enclosed, the case is filled up with a certain quantity of oil which the gear churns up, causing waste of power and heating of the oil, while spigots and centre bearings are dried out and wear or seize. In order to overcome these defects, the gear-shaft has been drilled right up to the after bearing, which is lubricated by forced feed from the engine system. The oil which escapes from this bearing serves to lubricate the ball thrust at the after end and the actuating gear for the clutch at the forward end. The spigot is under direct pressure, and there is plenty of oil passing through into the enclosed gear-housing, which it fills and keeps full under pressure, so that when the gears are moving they are running entirely submerged. Here again the oil escaping from the after bearing of the housing has to pass through the clutch plates, which are therefore kept well lubricated, while the oil escaping from the forward bearing helps to lubricate the starting gear. All bearings, therefore, have an ample supply of oil, the most important, the spigot, being the first to be served, while the gears are kept drowned, and churning of the lubricant is entirely avoided. One result of drowning the gears, accompanied as it is by good gear-cutting, is that the reversing-gear pinions run without noise, and, as far as gear noise is concerned, it is impossible to tell whether the reversing gear is running ahead or astern, or is in neutral.

The various features of this engine may be summarised as follows:—

1. It is spray-proof.
2. It is submersible to a certain amount, in fact it might be said, for all practical purposes.
3. It has no hot points to cause burning or excessive temperature in enclosed places.
4. It is entirely self-contained and enclosed, and all motions and controls are enclosed, protected and lubricated.
5. The actual controls and manipulation are arranged and carried out in accordance with the requirements of a marine engine.
6. The temperature of the water jacket is self-regulating.
7. The engine is designed to run for long periods at full power or to run light for an indefinite period under adverse conditions.
8. The starting is both by hand and mechanical, and the mechanical part is independent of any outside supply such as air-bottles or accumulators.
9. The crankshaft bearings being lightly loaded and well lubricated should, in the ordinary way, need very infrequent

FIG. 19.—Reversing gear.

FIG. 20.—Reversing gear showing brakes.

attention; nothing has, therefore, been sacrificed for accessibility to these parts.

10. On the other hand, those details which may require attention, such as the valves and the ignition, are situated where they can be readily examined and dealt with, and this has been done by placing the whole of these parts on a detachable head which can be removed without breaking more than one joint, and replaced without upsetting the adjustment of these parts.

11. The construction of the engine provides a rigid, substantial unit with good jackets and a satisfactory induction system.

It will be understood that an engine of this kind cannot be made as light as a bare automobile engine, but complete with reversing gear it weighs 36 cwt. and develops continually 89 horse-power at 800 revs. per minute, while the peak of the power curve is reached at about 980 when the output is 100 h.p. At the former figure the consumption is 0.7 pints of petrol per horse-power per hour.

The brake mean effective pressure is 88 lb. per sq. in., but the indicated mean effective pressure and therefore the mechanical efficiency cannot be given. In this particular engine, however, by running three cylinders at a time, this figure had been computed to be 118 lb. per sq. in.

The overall length from the forward end of the engine to the after coupling is 8 ft. 9 in., the height above the shaft line 3 ft. 3 in. and the depth below 12 in., while the width over bearers is 2 ft. $4\frac{1}{2}$ in.

It may be of interest to note that a jig has been made for this engine which is lined up in the boat in the position required. With this jig the stern tube hole is finished off, and the bearer bolt-holes are drilled, and as every pipe connection has a facing on the jig, all pipes are made and fitted before the engine is delivered. The various projections on the engine, and such items as the bilge suction, are reproduced in order that they can be provided for, the result being that when everything is finished, the jig can be removed and the engine dropped into its place and coupled up.

In conclusion, the author desires to express his thanks to Mr. A. C. Butcher for the care which he has taken and for the skill which he has shown in the preparation of the design of this engine, and to congratulate him on the manner in which the tests went through without one single mechanical hitch of any importance.

THE DISCUSSION.

Mr. W. F. DRAYSON, in opening the discussion, said: I have tried in vain to find something to criticise in this engine, and I must heartily congratulate the author and those who have collaborated with him in the design. I had a good deal to do with the design of the original engines, in fact they were nothing more than 'bus engines, practically as they are running on the streets of London to-day. I am not quite certain whether the auxiliary starting engine is to be used if the hand starting fails or whether it is used just in the ordinary way. I should prefer compressed air for starting, but I have no doubt the author has very good reasons for not using it.

Captain A. C. BURGOINE: I know that the author has worked very hard for something over twenty years to get thoroughly reliable marine engines, starting with a little two-stroke engine of about 1 h.p. From that, he has worked up to the fine engine described in the paper. A number of years ago I tried to make engines which were rather better than the ordinary marine engine of that date but they were a failure, not because they did not run well, but simply because I could not sell them, as people would not pay the price, and that, I believe, is still the case. The ordinary reversing gear in a marine engine is, as the author says, an abomination. Usually, it is a combination of cast iron and soft steel, with no proper means of lubrication or adjustment. I would like to suggest that the plan which was adopted for starting big aeroplane engines might be used for starting these lifeboat engines. The set consists of a small two-stroke engine with a compressor cylinder mounted on the same crankcase, which, instead of being open to the air, draws gas from the carburettor of the starting engine and delivers it through non-return valves to the big engine, which has to be barred round for a couple of revolutions in order to charge all the cylinders. The ignition is then switched on and the engine starts. A plant weighing about 45 lb. will start a 1,000 h.p. engine comfortably, and I should think that one weighing 30 to 35 lb. would start the lifeboat engine described in the paper. Such a compressor might also be used for compressing air only, which could be passed through an exhaust heat regenerator for working the capstan. I believe that it is proposed to fit wireless in some of these lifeboats, and this will introduce a further difficulty, as it will mean that the ignition system will have to be screened, and all the leads will have to be enclosed in metal sheathing or covered with wire braiding.

Lieut.-Col. D. J. SMITH: I was very pleased to see that the

(Lieut.-Col. D. J. Smith.)

author referred to Mr. F. C. Blake. I do not think that Mr. Blake has received sufficient credit in connection with the development of the marine petrol engine. He was one of the pioneers of automobilism, and I was therefore all the more pleased to hear that an engine designed by him in very early days is still running and doing good work. Mr. Blake was busy on this work as early as 1895, so that I think he deserves to rank as a pioneer in engine design. From my own experience with marine motors, I am not surprised that the Lifeboat Institution had to design a special engine when they wanted one that would stand up to their work. In a boat on which I was carrying out some experiments, I had a number of troubles which never ought to have occurred. They were troubles of design, and I can only imagine that the man who designed the engine had never been on a boat in his life, and had designed the engine in the drawing office and did not care what happened to it afterwards. One trouble nearly caused the loss of the boat. The oil filter was situated underneath the engine, between the bearers, and could only be got at through a hole in the crankcase web, through which a man could put one hand only. This filter choked in a heavy sea, and the engine had to be stopped to enable the mechanic to clear it, which he could only do with the utmost difficulty. Such a difficult job is naturally only done when absolutely necessary and not as a regular thing as it should be. Another difficulty was in starting up. The engine had six cylinders, $5\frac{1}{2}$ in. bore, and such an engine is practically beyond the power of a single man to start up, and yet no other means of starting was provided. There was only one man in the works who could start up this engine, and when he was absent it was impossible to get the engine started. Such conditions may, of course, in a commercial craft mean the loss of the boat. In the case of a lifeboat, it may mean the loss of the crew and the loss of the lives of the people they set out to save.

Dr. W. R. ORMANDY: I am pleased that the author has brought into prominence the fact that the average marine engine is not all that might be desired, though it is obvious that the requirements of a lifeboat motor are considerably more severe than those which obtain with a motor for more ordinary purposes. There is no doubt that engines which have hitherto been employed as auxiliaries on board ship have been far inferior to the engines supplied for motor car work. The subject of accessibility is much more important at sea than on land, and yet accessibility has been less studied in marine engines than in any other type. The strictures passed by the author on the average reversing gear are fully justified. Ignition troubles have been frequent, and, generally speaking, the bulk of the fittings have not been equal to the duty they are called upon to perform. It is rather a disgrace that a sea-going nation like ours should have neglected this side of the development of the internal combustion engine. The

market is, of course, compared to cars, comparatively small, but it is difficult to say how far the use of internal combustion engines afloat has been delayed by bad design, poor materials and high prices.

Engineer-Admiral RUDD: We have had some remarkably good results with some of our motor lifeboats. The most notable case was during the war when the "Rohilla" hospital ship went aground off the Yorkshire coast, and from the lifeboat stations in the vicinity the ordinary sailing lifeboats put out to save life. These boats got near the ship and got a few people off, but the sea got up so badly that the sailing boats had to sheer off and the ship remained for forty-eight hours with 90 to 100 people aboard. As a last resource the motor lifeboat, about 42 ft. long, was ordered down from Tynemouth. This boat came down in the middle of the night without any lights and with no lights on shore to guide them. She did the 64 miles in about nine hours and got down in time, and in the morning got near enough to rescue the whole of these people and bring them ashore. That is about the finest piece of service a motor boat has done in recent years, I believe, and it shows the use of the motor lifeboat. There seems to be pretty general agreement that it is practically impossible to get a good marine motor engine, and nobody seems to have taken the trouble hitherto to design a simple engine without too many complications that are liable to get out of order and cause a breakdown of the boat. This new engine is a very fine one, and I hope that we shall find it a thoroughly reliable one.

Mr. L. A. LEGROS: The paper is one of the most absorbing interest because it deals with the vital element in a motor boat designed to work under conditions that are extraordinarily difficult. The engine of a lifeboat is required to run, and to keep running, in a boat which must be invertible, submersible, arrestable and reversible. This is a big order in itself, but it must further be remembered that, in addition to performing this duty, the weather is selected by nature herself, of the worst kind, not merely for trial, but whenever the boat has to execute that duty for which it has been constructed. To those with very limited experience of motor boat building, the conditions will appear almost impossible to satisfy; to those who know more of the subject, they will appear still worse; every conceivable factor is against the lifeboat, and the accomplishment of the task set to the author is one of the finest records of achievement by sustained effort.

In an ordinary motor boat every auxiliary detail goes wrong or gives trouble apparently without provocation or neglect when at sea. Even if the engine were beyond reproach, tanks and connections start leaks, the brass work becomes damaged by the sea water and the wood-work warps or splits through the action of the sun and weather, while the electric ignition gear suffers damage by corrosion of the contacts of the leads, and is liable to short-circuits due to the effect of damp. In addition to this, whereas

(Mr. L. A. Legros.)

a car engine may be hard to start on shore, this difficulty is apparently doubled when the same size of engine is put in a boat and the operation must be performed with restriction of freedom and disturbance of equilibrium, and this trouble again is augmented by the bad weather in which the lifeboat has to work.

The only point on which I can see a possibility of improvement is in the adoption of compressed-air starting for operating three of the six cylinders. I suggest that a couple of storage cylinders about 18 in. dia. by 6 ft. long and 0.16 in. thick which could be charged to about 220 lb. per sq. in. should be tried experimentally for starting the engines; they could weight about 3 cwt. empty and about 25 lb. more when charged, so that they should not impair the flotation of the boat, but they would be available to start the engine or to supplement the efforts of the competent men who might be temporarily in a position of disability to get the engines going again in the event of a stoppage in rough water. Probably the author has considered this possibility, and I make the suggestion merely from experience of the difficulty of starting an engine by hand in a heavy sea, and not as a criticism of what should be regarded as a masterly solution of one of the most difficult problems ever brought before the automobile engineer.

Mr. O. D. NORTH: I feel that it is only necessary to look at existing marine engines and drawings, and to hear the experiences of the users, to realise that the manufacture of marine motors—with a few prominent exceptions—is associated with a low grade of engineering and a low standard of design and material. Many of those who are making motor boat engines, mostly on a small scale, would not trust themselves to build a car engine. I should have liked to hear a little more from the author about his troubles with high-tension ignition. Is it the shorting through the moisture of the air on the outside of the plugs, on the leads, or is the trouble in the high-tension apparatus itself? I take it he has got rid of the last trouble by the enclosure of the Delco coils, which, I imagine, are also cased in Bakelite or similar material. One trouble with low-tension ignition was the difficulty of getting a good enough contact inside the cylinder before the contacts open again if the engine is oily, even though the insulation resistance does not have to be anything like so high. There is one point I would like to criticise in the author's engine, assuming it were put to ordinary commercial use. He has provided very large main bearings and excellent lubrication, and he apparently trusts to that provision to secure immunity from bearing troubles, considering accessibility to be of secondary importance. I have no doubt he is perfectly right as regards lifeboat motors. Though they work under very arduous conditions, they run on an average only 100 hours a year. In commercial service, such as a motor tug boat, that would represent about a week's work. With a good lubricating oil and no experimenting with cheap fuel no bearing trouble would be anticipated in such a short period, but I do feel

that for ordinary commercial work—and it seems to me that people who build marine engines ought to make them suitable for commercial motor boat work—there should be better access to the bearings. I would suggest that instead of putting the cylinders upright they should be inclined at, say, 30 degrees to the vertical, with all piping on the “upper” faces and the big ends, crankshaft bearings and shaft itself removeable through a large cover-plate running the full length of the engine, which would make them very accessible. I am a little disappointed at the rather complicated nature of the main crankcase casting; it embodies, for instance, both the exhaust manifold and the inlet manifold, but since the air inlets are very high up I do not quite understand why the carburettors are not attached to the manifolds on the cylinder head, thus raising them also above the level of the possible flooding of the engine room. The auxiliary gear of the engine seems a little complex, though I admit I have not a simple solution of the problem; I do not like the use of bevel wheels at each end of the crankshaft. The great objection to compressed air starters. I should imagine, is the cooling of the compressed air when it expands. At sea that would be very much more serious, because the air drawn in to produce the mixture is apt to be humid, and if the cylinder is cooled moisture is liable to condense on the ignition plugs.

The PRESIDENT: I was surprised to see that there are four feet on each side of the crankcase for carrying the engine. I should have thought that the working of the boat in a rough sea would tend to break off one or more of these feet in time. A continuous bedplate, which is more or less standard practice for steam engines, would appear to have been the better plan to adopt. I was very glad to note that the designers of this engine have profited by the work of other people in small details, as it is only by ignoring the failures and adopting the successes of others that we arrive at really satisfactory results. One of these details is the duplex filter, which I believe was designed by a colleague of mine some years ago for a condition somewhat similar to those which obtain in motor lifeboats, where the oil was frequently fouled by water or dirt and the filters required to be cleaned regularly; a filter almost identical with the type shown in Fig. 17 was adopted. The author stated that he was surprised that his governor turned out so sensitive. I had a little experience with this type of governor some time ago, and I also was surprised at its sensitiveness for a short time, but grooves were very quickly worn and instead of being a governor it was a sort of step-up gear, and it actually jumped from one range to another and hunted very badly. It would go from 500 to 800 or 500 to 1,000 revs. per minute, and there was no question of any intermediate range at all. None the less, the engine embodies a lot of serious and well thought out work and strikes me as being an excellent example of good sound engineering.

(Mr. Butcher.)

Mr. BUTCHER, in replying on the discussion, said: Mr. Drayson asked if the starting engine is to be used as a primary means of starting or as a standby. It is intended to be used as the primary means of starting, the starting handle being the standby. The engine can be started either through the little motor, or through the starting handle direct, or the two can be used in conjunction, i.e., the starting lever can be used to boost up the power of the small engine, if necessary. Mr. Drayson also mentioned air starting. It should be borne in mind that we may have occasion to start this engine many times in one trip. We may be standing by a wreck perhaps for hours, and it may not be necessary to run the engine all the time. We may have to start up just to pull away from the wreck, depending on weather conditions, etc., and on one trip it may be necessary to start up twenty or thirty times. The capacity of the air reservoir which we should have to carry to contend with contingencies of that nature would be very great, more especially as in order to get this engine cranked round at approximately 60 revs. per minute requires 180 to 200 ft.-lb. torque, or allowing for the efficiency of the mechanism, about three horse-power. Moreover, there is additional engine mechanism required to operate any air-starting apparatus; there are the valves inside the cylinder which are likely to become carbonised and leaky, which, of course, is a dangerous fault common to practically all air-starting apparatus.

Captain Burgoyne's suggestion of pumping explosive gas into the cylinders is certainly a much better proposition than direct air starting, but this method also introduces extra engine valves and distribution mechanism in addition to the starting motor and compressor. He mentioned the fact that 40 or 50 lb. was the weight of the air-gas starting apparatus. Our apparatus weighs less than 40 lb., which weight includes all the operating mechanism for the starting gear.

The faults of design mentioned by Lieut-Col. Smith are unfortunately only too common in the majority of marine engines. I quite agree with him that a $5\frac{1}{2}$ in. engine is too big to be comfortably started by hand by one man, and certainly an engine of this size should be provided with some mechanical or electrical means of cranking.

Dr. Ormandy mentioned reversing gears; undoubtedly the majority on the market to-day are, as he says, by no means reliable. It was through the disappointing experience we had with them that we decided to concentrate our efforts upon making a real engineering job of our gear. We have introduced pressure lubrication throughout; there is no churning of the oil inside the gear casing, and the gear is running under the same definite pressure of oil as the rest of the engine. On the engine generally, that is, the engine and reverse gear, we have thirty-seven points at which pressure lubrication is applied, and about seventeen open ends which the pump has also to deal with.

Admiral Rudd also referred to the difficulty of getting a good marine engine. It is not merely a question of getting a good engine and one of sufficient power. The engine has to be reasonably efficient, but it has certainly to be super-reliable. That has been our ideal right through. It has not been so much a matter of a super-efficient engine, that is, from a fuel and oil consumption and weight per horse-power point of view, we have not been striving for that. We have been striving to get an engine which is really efficient, at the same time having as our primary object reliability.

Mr. North spoke of the low-grade design of marine engines, and I think we all agree with his remarks. Undoubtedly, marine engines as existing in this country and in America and other countries are poor, especially in matters of detail. The accessories seem to have been stuck on just anywhere and anyhow. He also spoke of the engine not being as accessible as it might be if used for commercial purposes. I think he has rather formed a misconception of the design. As the author stated, it requires only one hour to get out the whole of the six big ends, connecting rods and pistons. That has been done on the test bed. We would not, however, expect to do it in quite so short a time on a lifeboat where there is a limited space to operate in. The question of inaccessibility would not apply to these engines as commercial engines, as in commercial use there would be a substantial amount of room to get round the engine to make adjustments; when it is realised that there are three openings 6 in. wide by 8 in. high on each side of the crankcase, it will be appreciated that it is not inaccessible as far as the interior is concerned. If necessary, the four main bearings may be removed through these doors; that operation has actually been done. It certainly is not an easy job, but they have been taken down and replaced without removing any portion of the mechanism other than the oil pipe, in a day, so I do not think the question of inaccessibility of this engine is really substantiated. What we have been aiming at, is to produce the Rolls-Royce of the marine world. Mr. North also mentioned that the bearings would probably run for five years under lifeboat conditions. It is not five years that we expect but twenty-five years or more, and certainly we do not expect to have to renew a bearing in the lifetime of the engine. Both the big-end and the main bearings are operating at an average pressure of under 300 lb. per sq. in. with a maximum on the big ends of 1,100 lb. per sq. in., so that bearing troubles, apart from lubrication difficulties, should be more or less non-existent. He also mentioned the fact that starting on compressed air was likely to produce moisture troubles. This was one of the difficulties we had in mind when we were considering compressed-air starting. The conditions of atmosphere and sea under which lifeboats go out are usually such as to produce a very salt-moist air, the condensation of which would be likely to give rise to endless trouble.

(Mr. Butcher.)

It is certainly interesting to hear the President's remarks with regard to the governor and the step-up arrangement. I presume this was probably due to the fact that only one element was rotating and not the two elements in unison. In our design we have the two elements locked together, and the only relative motion between them is the sliding motion, caused by the balls forcing one plane away from the other. All the wear in the governor is automatically compensated for, and the only adjustment required to be made is the adjustment of the control spring to suit the speed required.

Mr. EVANS, in further replying on the discussion, said: Mr. Drayson rightly stated that the first engine used by the Lifeboat Institution was a 'bus engine, as it was designed and sold mainly for this class of work. The last series of engines which we installed, however, were nothing but standard commercial-vehicle engines, altered in certain features to comply with salt water and marine requirements; for instance, a gun-metal wheel pump was fitted, new water manifolds were provided, a governor was added and so on, but they were none the less 'bus engines, and are doing excellent service, as we have provided the necessary equipment to keep them going.

Captain Burgoyne's remarks take me back to the time when Mr. Blake launched the *Vitesse*, the first four-cylinder motor boat on the river Thames, and a great advance on contemporary engines; there is no doubt that she indicated to us, who were struggling with the American two-cycle engines, that there was something much better ahead. I give Blake the honour of being the pioneer of the serious marine motor.

The little 1 h.p. two-stroke engine which Captain Burgoyne mentioned was in fact a 1.7 h.p. engine imported from the States, and was fitted in an eighteen-foot boat in the year 1899 or 1900. It was in regular use up to the beginning of the war, and it never let me down once. This was not because it was well made, for the engineering was about as bad as could be, but it had certain essential "marine" features, and was in fact a marine engine, and as such it filled the bill better than any engine that I know, even up to the present date. Almost the last time that I used the boat was in the winter, and the circulating pipe froze solid, and I came home by scooping water out of the river and pouring it over the engine. The engine itself was frost-proof owing to a very simple arrangement, it was damp-proof, had no hot spots and could not be rusted up. If that engine had been manufactured properly, I am sure that it would have become a standard, but though I hawked it all over the country I could not get any substantial engineering firm to take it up.

Our experience with high-tension ignition is nothing more than a record of the effect of salt water and sea air on high-tension gear. There are, of course, no really waterproof magnetos; I

have come to this conclusion from the fact that I can never induce the representatives of firms who offer us samples to squirt water at them with a syringe. We find the cost of upkeep of high-tension magnetos very high, though we are getting better results with a low-tension magneto and a single coil and distributor.

Rubber-covered wires are no good amongst petrol, oil, sea water and brass polish, though our ebonite wire helps. What is wanted is an oil-proof, heat-proof and water-proof low-tension flexible wire, which is not on the market yet, and the Lifeboat Institution have had to get some made up to their specification.

Switches, etc. also give trouble; the motor compartment temperature is about 100° F. and this is bad for ebonite, though when we can get fittings made up in Bakerite cases with the sealing medium put in under a vacuum we have very little trouble. Distributors are never made waterproof, but we have eliminated our sparking plug troubles by fitting a special protector that is waterproof. I have seen an engine with high-tension ignition started up in the dark before special wire, etc. had been fitted, and it seemed all alight with surface leaks, and we have had petrol explosions from the same cause.

Our low-tension ignition troubles are mostly detail mechanical faults due to incorrect design. In the early days, vulcanised fibre was used for insulating, and it let us down badly and we had constant battery troubles, but water, carbon, oil, or dirt on the contacts make very little difference.

It was asked why we did not go in for three-point suspension; I could not say, except that we were somewhat afraid of making such a departure, though I certainly think it is the right thing, and as soon as it has been proved by some substantial firm in an engine of this weight we shall certainly amend our design.

The Duplex filter would appear to be obvious; anyway, it has been used with marine Diesel engines for some time, and as a matter of fact we designed one in 1915.

As to accessibility, I am afraid that I presented this point very badly in the paper. What I meant was that we set out to make the important details which require regular attention quite accessible, and we were determined to make them accessible even at the expense of the crankshaft. However, we were able to do all this and yet leave everything clear for the removal of the main bearings, pistons, connecting rods, etc. in a minimum of time and without taking down any parts that were in no way concerned.

Mr. Legros was good enough to compliment us on this effort, but it is quite easy to carry out an enterprise of this kind when those who are controlling the policy of the concern are able to recognise fundamental facts, and only insist upon the best that can be done.

COMMUNICATION.

Mr. G. STEINHEIL wrote: Seeing that the engine has to withstand the action of salt water, I wonder whether the question of application of rustless steel for certain parts of the engine was considered.

I do not quite agree with the author's method of starting the main engine. Although the small two-stroke engine is supposed to start up the main engine, still that engine has to be started by hand, and that may sometimes take ten minutes. I think, therefore, that compressed-air starting would be a simpler proposition, especially in the case of large lifeboats fitted with an air-compressor auxiliary set which supplies compressed air for driving the capstan, etc. I do not suggest that the compressed-air pipes should lead direct into the main cylinders, as that would complicate the design of the main engine, but I think it would be quite a feasible proposition to run the auxiliary starting engine as an air motor, which would start the main engine through the gearing described in the paper.

In reply to the written communication, Mr. BUTCHER wrote: In reply to Mr. G. Steinheil's communication regarding the use of rustless steel, the question was very seriously considered, and in fact we have utilised it in one or two isolated places which are likely to receive little or no attention. We should, however, have made far greater use of it had it been commercially obtainable in standardised qualities. At present there is no standard whatever for this steel, and a reputed similar material obtained from two different sources will give widely varying results. When the British Engineering Standards Association decide some definite standards for it, we shall then have something to specify, although there is no guarantee that we shall be able to get the materials they lay down, as we have experienced considerable difficulty in obtaining in small quantities even such steel as E.S.C. 20.

With regard to using the starting engine as an air motor, this might be possible in the larger boats equipped with auxiliary compressing plant; it certainly could not be used otherwise, as apart from other difficulties previously mentioned, it would require, to develop the necessary power, something like 85 cu. ft. of free air per minute, which even compressed to 300 lb. per sq. in. would involve quite cumbersome storage tanks to look after, say, ten or twelve runs of about one minute each.

FIG. 1.—Stern tube, showing sleeve over propeller boss.

FIG. 7.—Detachable head.

FIG. 10.—New six-cylinder engine.

FIG. 18.—After end of engine.