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The High-Speed Light-Weight Diesel Engine

Commander(E) J. H. D. MIDDLETON, R.N.(ret) (Member)

The possibility of making Diesel engines light enough to challenge the petrol engine for use in aircraft became apparent in the early 'twenties, and the Beardmore engines of the "R" class airships, and the Mercedes-Benz engines of the Transatlantic Zeppelins are early examples of such machinery.

By 1939, however, it was clear that the Diesel engine could not compete with the petrol engine for use in military aircraft. But the need for machinery of this general type for use in light Naval craft was growing, and U.S.A., Germany and Great Britain set about producing suitable engines.

The paper describes and illustrates the General Motors Model 16-184A (the "Pancake"), the Mercedes-Benz type MB.511, the Junkers Jumo 205E, the Paxman-Ricardo "Ex 239A", and the Perkins T.12.

Their design features are discussed and contrasted, and suggestions made as to why the foreign engines went into production and the British did not.

It is suggested that there is an immediate need for an engine of about 2,000 b.h.p., with a specific weight of 3·5lb. per b.h.p. The possibilities of producing such an engine are discussed, and an outline design is put forward for consideration.

INTRODUCTION

For the past twenty-five years or more the Diesel engine designer has been absorbed by the idea of ousting the petrol engine from one of the fields where it reigned supreme, that of aircraft propulsion, where low specific weight is the dominant requirement. The problem is not so impossible as might be thought because the greater economy of the Diesel will do much to retrieve the handicap of its inevitably more robust construction since, in these applications, the weight of the machinery plus the fuel for a stipulated number of horse-power-hours is the vital quantity. Thus beyond a certain critical range or endurance, the Diesel will show an advantage from the weight view point, although it will still be considerably heavier than the petrol engine without its petrol. Once this principle requirement could be satisfied, there are many other advantages which the Diesel engine could offer—simplicity in construction, elimination of vital electrical auxiliaries, fuel of lower volatility—which will give greater safety from certain hazards and, perhaps, greater reliability. Many Diesel enthusiasts insist that a Diesel engine is more reliable and will go longer without service and overhaul than the corresponding petrol engine. The author's experience is that reliability, in machinery of comparably skilful design, is inversely proportional to the specific weight and is largely independent of the cycle used.

Perhaps the first successful displacement of the petrol engine was achieved by Chorlton's Beardmore engine which was used in the British rigid air ships of the nineteen twenties. The quest was taken up by the Germans and Mercedes-Benz developed an engine for the post-war transatlantic Zeppelins while Junkers concentrated on engines for aeroplanes. Both these firms achieved a very real measure of success and soon saw that there were other fields of application which might produce fruitful results.

Thus Mercedes-Benz became interested in railway traction and, eventually, in marine propulsion. In the latter application they achieved the zenith of their development with their model 511 which powered the E-Boats of the Kriegsmarine with a power of 2,500 b.h.p. on a specific weight of 4·2lb. per b.h.p.

Britain and America discarded the Diesel engine for aircraft once it became clear that it would not compete with the petrol engine for military purposes. This was a distinct setback for the development of the light weight Diesel in these countries but, in the late 'thirties, it was realized that a marine requirement could be met by such an engine and various designs were produced. Neither of the British designs went into production but the Americans produced, in 1942, the well-known General Motors "Pancake" Diesel.

It is the object of this paper to give some details of these

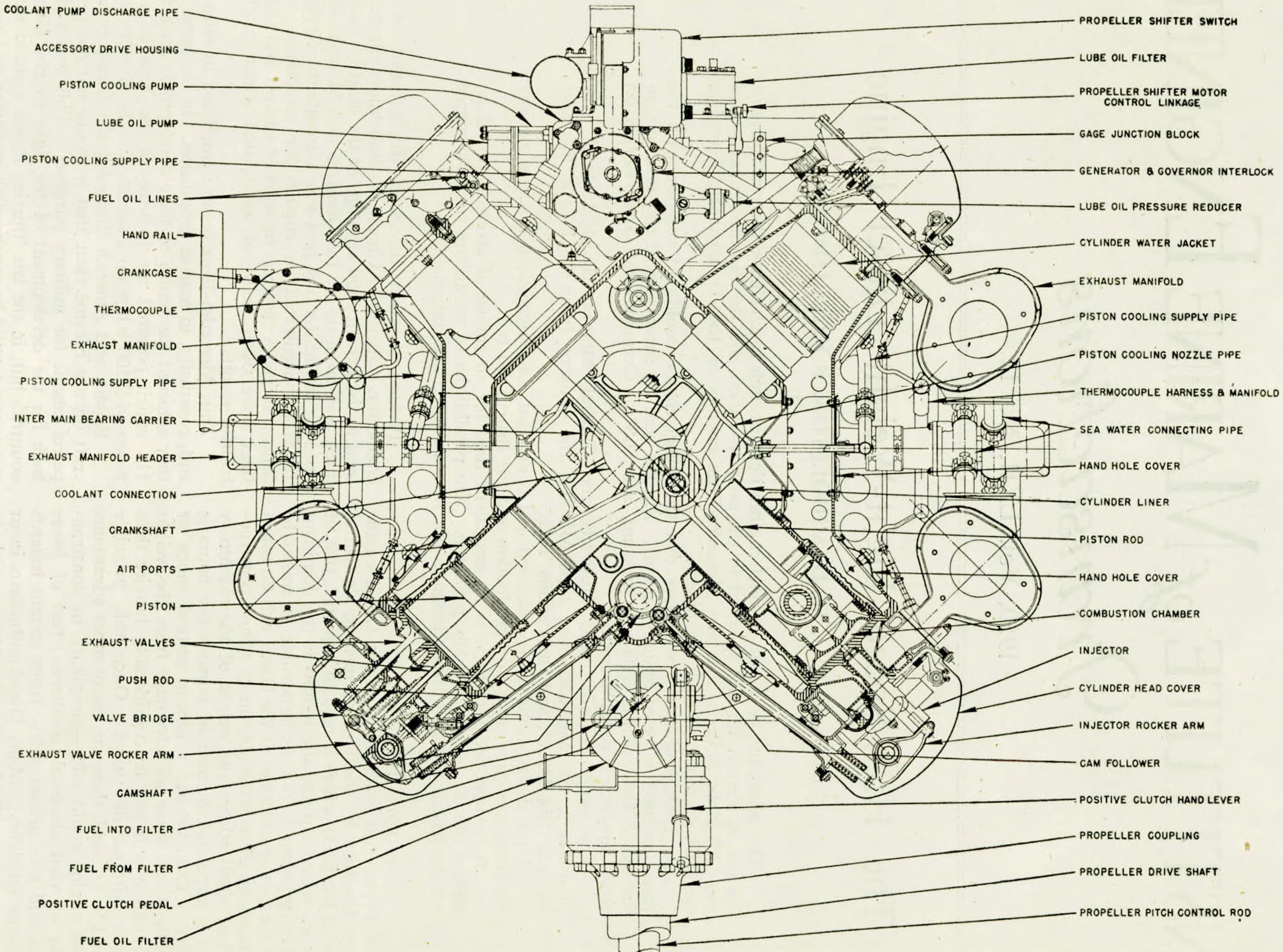


FIG. 1—*General arrangement—horizontal section*

designs, to appraise the current problems and to suggest possible future steps.

THE GENERAL MOTORS MODEL 16-184A (PANCAKE) ENGINE (SEE FIGS. 1, 2, 3, 4, 5 AND 6)

Cycle	Cylinders	Type
2	16 (4 banks of 4)	Single acting trunk piston through scavenge
Cooling	**Bore and stroke, in.**	**Max. h.p.**
Liquid	6×6¼	1,200

B.m.e.p., lb. per sq. in.	R.p.m.	Piston speed ft. per min.	
90	1,800	1,950	
H.p. per sq. in. of piston area	**Litres**	**Weight, lb.**	**Sp. wt., lb. per h.p.**
2·65	46·4	4,902	4·1

The general shape and arrangement of this engine will be appreciated from the Table above and the illustrations.

Despite all the adverse comments on the design of this engine it was made in considerable numbers and, as far as the author knows, ran very well. The American Marine service rating (quoted above) was considerably below the design point and, to that extent, it was a disappointment. There was a small

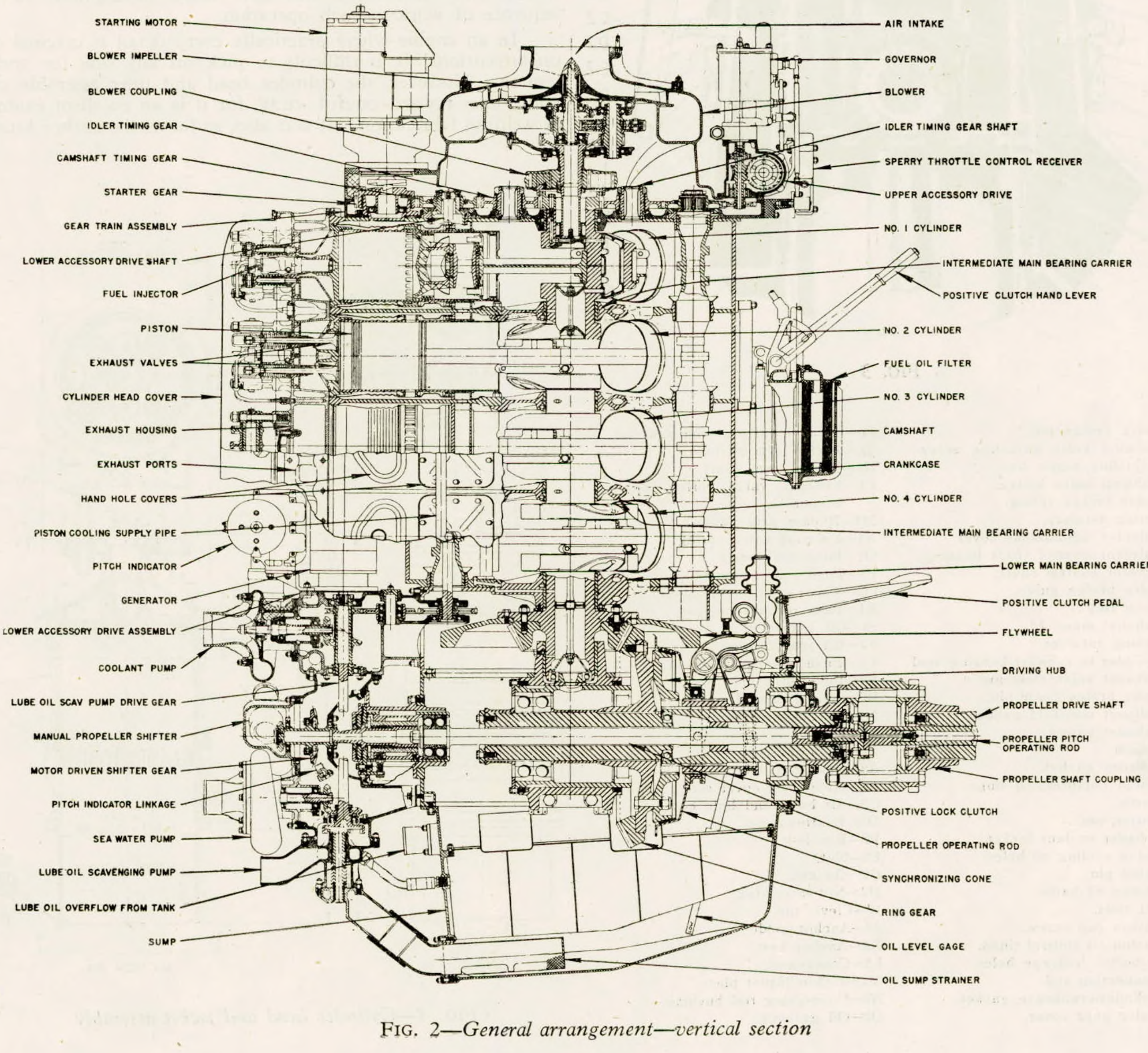


FIG. 2—*General arrangement—vertical section*

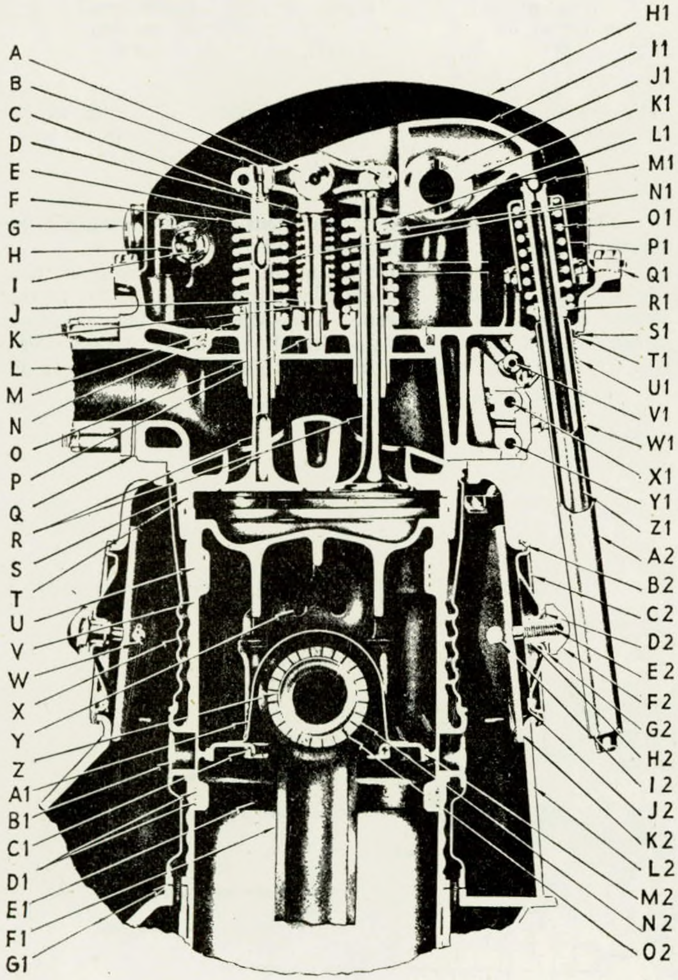


FIG. 3

A—Valve bridge pin.
B—Exhaust valve adjusting screw.
C—Adjusting screw tip.
D—Exhaust valve bridge.
E—Valve bridge spring.
F—Spring retainer.
G—Injector adjustment cover.
H—Injector control shaft bearing.
I—Injector control shaft.
J—Valve bridge guide.
K—Snap ring.
L—Exhaust manifold.
M—Spring retainer.
N—Cylinder to exhaust housing seal.
O—Exhaust valve stem guide.
P—Valve bridge guide pin.
Q—Exhaust manifold gasket.
R—Exhaust valves.
S—Sodium
T—Cylinder gasket.
U—Piston compression rings.
V—Piston.
W—Cotter pin.
X—Cylinder coolant jacket.
Y—Piston cooling oil holes.
Z—Piston pin.
A1—Piston oil baffle.
B1—Air port.
C1—Piston cap screw.
D1—Piston oil control rings.
E1—Lube oil drainage holes.
F1—Connecting rod.
G1—Cylinder-crankcase gasket.
H1—Valve gear cover.
I1—Exhaust valve rocker arm.
J1—Rocker arm bushing.
K1—Rocker arm shaft.
L1—Exhaust valve spring retainer keeper.
M1—Rocker arm ball.
N1—Exhaust valve spring.
O1—Push rod spring.
P1—Push rod spring retainer
Q1—Valve gear cover gasket.
R1—Push rod spring seat.
S1—Oil seal.
T1—Oil seal flange.
U1—Push rod cover spring.
V1—Lube oil supply line.
W1—Spring seat flange.
X1—Fuel return line.
Y1—Fuel supply line.
Z1—Push rod.
A2—Push rod tube.
B2—Hand hole cover seal.
C2—Air box hand hole cover.
D2—Bearing ring.
E2—Eye bolt.
F2—Nut.
G2—Gasket.
H2—Nut snap ring.
I2—Clevis pin.
J2—Anchor guide.
K2—Anchor bar.
L2—Crankcase.
M2—Piston thrust plate.
N2—Connecting rod bushing.
O2—Oil grooves.

number of these engines in British Naval service during the war but neither the time nor opportunity was available for carrying out any performance testing on the brake. The craft fitted with them were employed on special service in the very far North and the author's information is that they gave very little trouble of any sort and certainly enjoyed the minimum of maintenance facilities.

The design, construction and installation of these engines must be reckoned as a masterpiece of American ingenuity. The engine was eventually produced in quantity at a very modest expenditure of labour because no attempt was made to produce the engine by traditional methods at an engine works; a factory was designed, jigged and tooled to produce the engine. The installation was extremely complex and included an electrically operated variable pitch propeller yet its operation was comparatively simple.

The advantage accruing from having the whole installation from propeller to throttle lever designed and made as an entity was very apparent. The complexity of the installation was no handicap on reliability because the individual components had been thoroughly developed and tested on shore; the kit of tools and special fixtures were adequate for any stripping and assembly which could be undertaken, outside an overhaul shop, and an instruction book was provided which was lavishly illustrated and gave lucid descriptions of the sequence of work in each operation.

In an engine where practically every detail is original and unconventional it is difficult to pick on any one for special remark. However, the cylinder head and liner assembly cortainly does reward careful study, for it is an excellent example of welding fabrication. It was also, as far as the author knows,

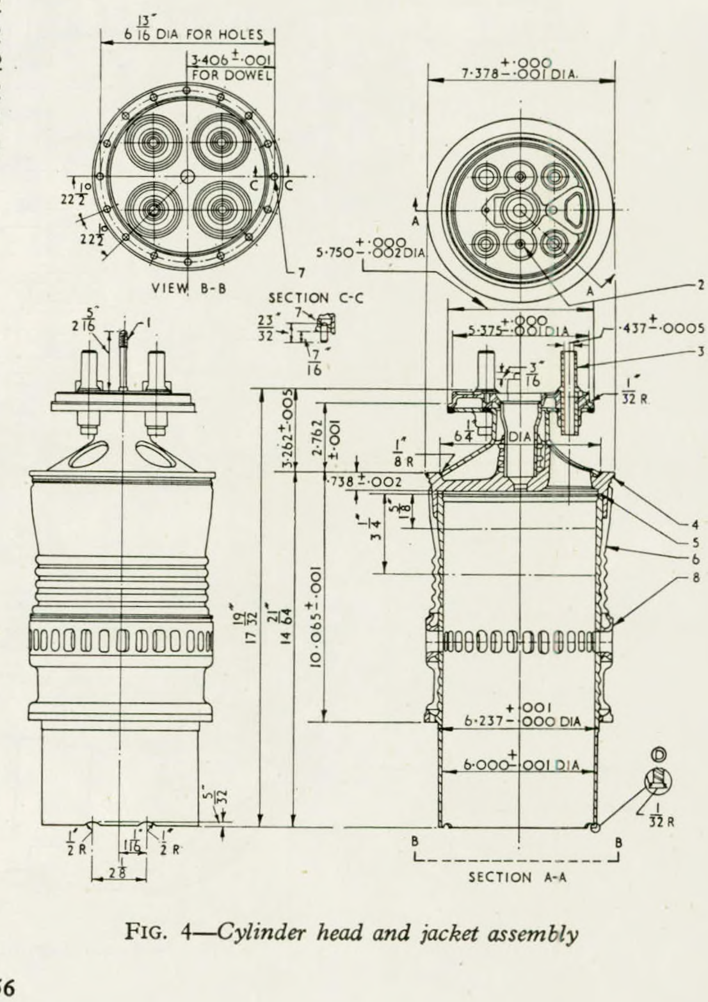


FIG. 4—*Cylinder head and jacket assembly*

completely satisfactory from the production and functional point of view.

The piston, however, may have been the Achilles heel of the engine. The idea behind the forged alloy steel head and steel skirt seems quite sound—to keep the piston crown hot, to remove excessive heat by oil cooling, and to create a heat barrier between the crown and the ring grooves by thin sections and a welded joint. Unfortunately, the heat barrier was not fully effective, or else the oil jets did not remove the heat at the anticipated rate or there was, perhaps, a combination of both these and the result was a distinct tendency to ring sticking if the engine was at all hard pressed. It would be interesting to see what output could be achieved using an aluminium alloy piston with "Shake" cooling and an oil of the heavy duty type.

Another feature of the piston which will be noted is the severity of the scraping to be anticipated from the ring arrangement. This was perhaps necessary, as the engines had a tendency to smoke when cold, but it was probably dictated by the amount of loose oil which would inevitably become detached from the fringes of the piston cooling jets.

The makers are still developing the basic design, and a new version of this most interesting engine can be expected before very long.

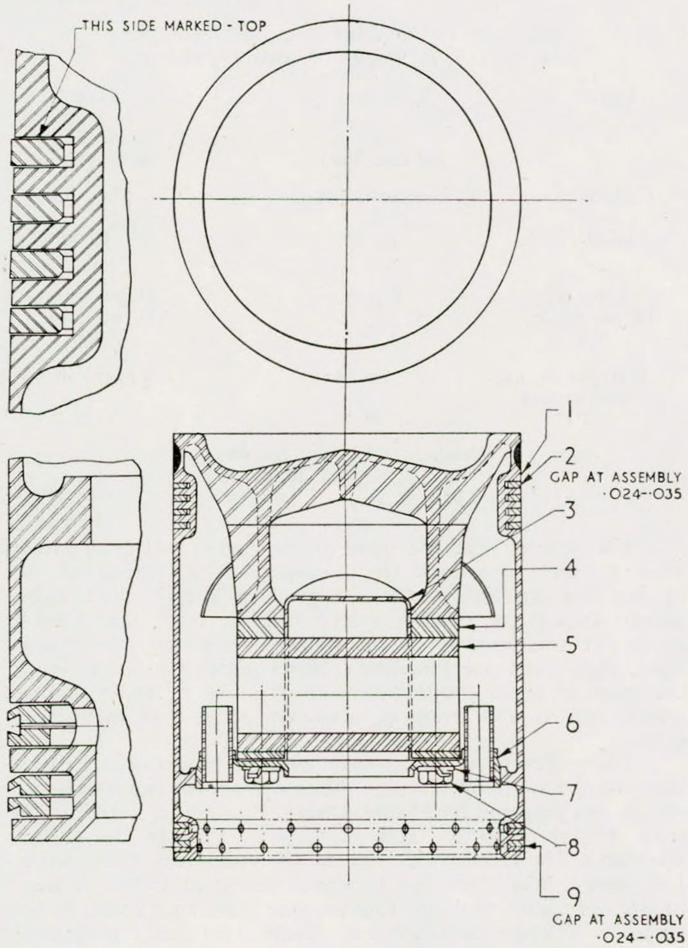
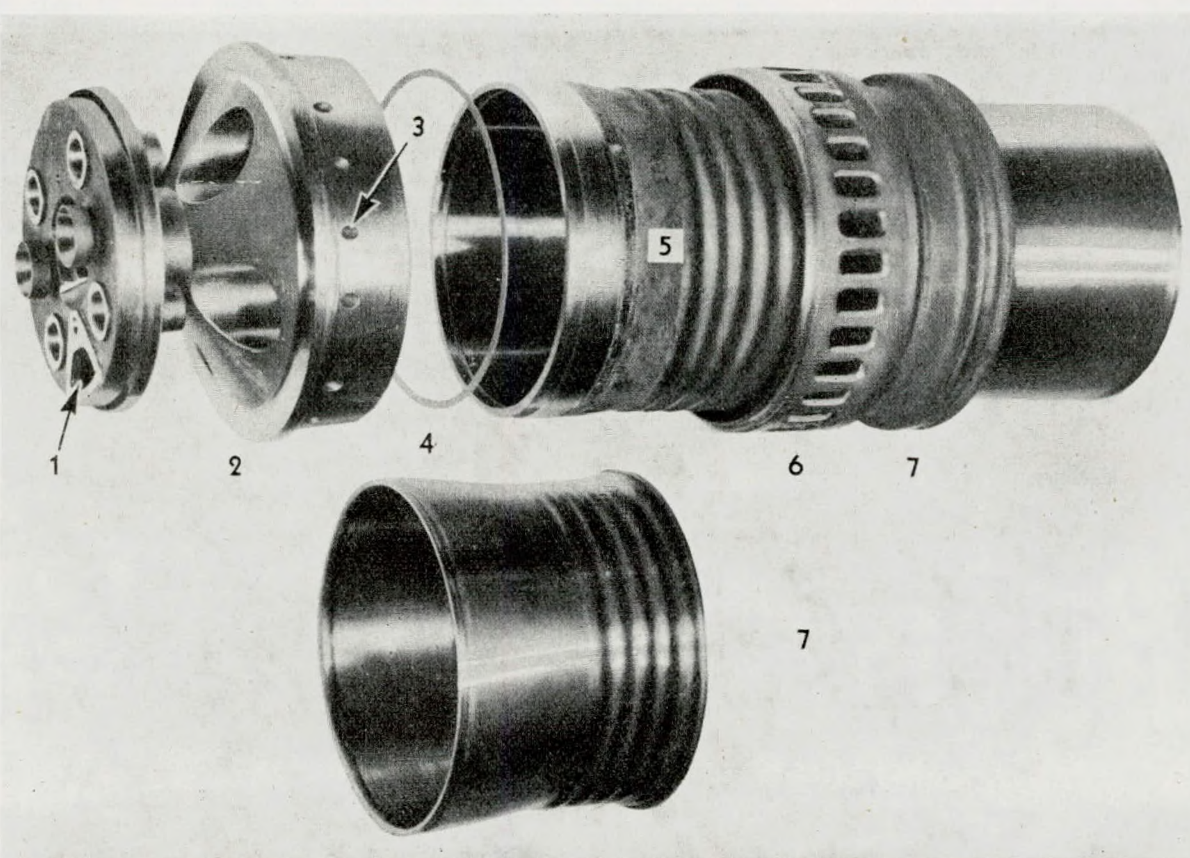


FIG. 5 (*right*)—*Piston assembly*

FIG. 6 (*below*)—*Exploded view of cylinder head and jacket*



THE PAXMAN RICARDO "EX 239A" ENGINE
(SEE FIGS. 7, 8, 9 AND 10, AND 11, PLATE 1)

Cycle	Cylinders	Type
4	12 (60 deg. Vee)	Single acting trunk piston
Cooling	**Bore and stroke, in.**	**Max. h.p.**
Liquid	$7 \times 7\frac{3}{4}$	1,000
B.m.e.p., lb. per sq. in.	**R.p.m.**	**Piston speed, ft. per min.**
126	1,750	2,260
H.p. per sq. in. piston area	**Litres**	**H.p. per litre**
2·16	58·6	17·5
Weight, lb.	**Sp. wt., lb. per h.p.**	
3,850	3·58	

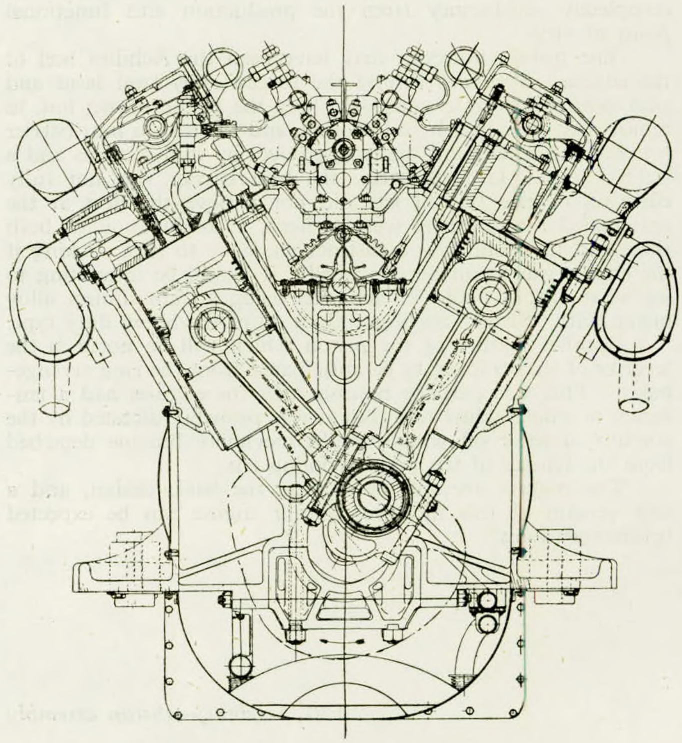


FIG. 8—*Cross-sectional arrangement*

The general type and form of the engine will be apparent from the table above and the illustrations. It represented one of the first British attempts to produce a high-speed light-weight engine for driving motor torpedo boats and similar craft. It was modest in its ambitions—neither particularly light, high-speed nor powerful. Nevertheless it failed to reach the stage of serial production and it is one of those failures which can, in some respects, teach one more than many successes.

The preliminary development work on a two-cylinder unit was carried out by Messrs. Ricardo. The multi-cylinder design was prepared by Messrs. Davey, Paxman in collaboration with Messrs. Ricardo, and built at Colchester by Davey, Paxman. The engine was sent to the Admiralty Engineering Laboratory, West Drayton, for development in 1939. A large number of minor teething troubles were experienced such as are common to every development. Some were cured by simple modifications affected on the spot; others were clearly of the type which are susceptible to treatment by re-designing certain components. But, in addition, certain major snags had cropped up which really called for fairly drastic steps.

By March 1940, the account could cast up something like this:—

(*a*) *Credits*

(i) The engine had been run up to its rated power and speed with a clear exhaust. The fuel consumption was on the high side, 0·45lb. per b.h.p.-hr.—which might indicate excess air, but this was not of primary importance and the excess air helped in piston cooling. It could therefore be said that combustion was satisfactory and distribution reasonably good.

(ii) The pistons had shown no signs of excessive thermal loading either in the shape of ring sticking or distortion which had been found to occur with the "comet" combustion system at high b.m.e.p. in larger cylinders.

(*b*) *Debits*

(i) The crankcase had fractured above the centre main bearing as an immediate result of porous metal in the casting. It was the opinion of the foundrymen that the design would require considerable modification before sound castings could be confidently expected.

(ii) Certain of the main bearings were clearly overloaded

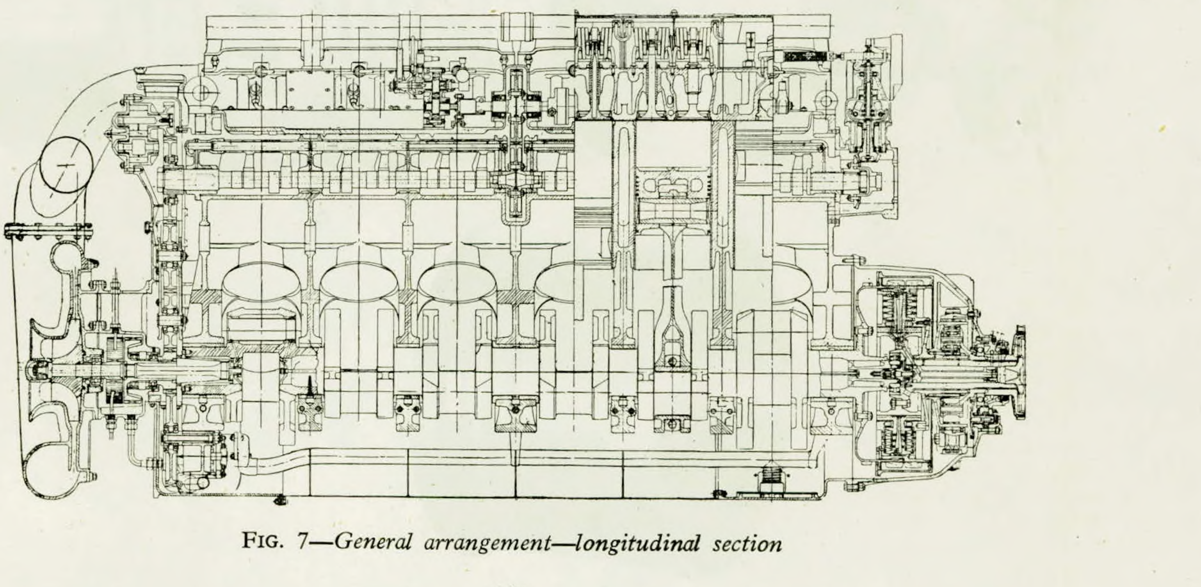


FIG. 7—*General arrangement—longitudinal section*

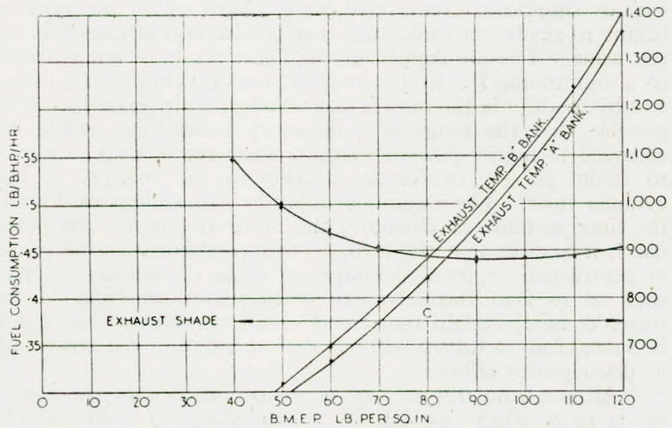


FIG. 9—*Performance curves*

PAXMAN ENGINE EX.239A

1,750 r.p.m. loop. 11¾ inch Hg boost. C.A.V. Bosch injection pump. 3 mm. elements, fast cam. Static timing 25 deg. b.t.c. Nozzle Type D.N.8.52. Opening pressure 1,800lb. per sq. in. Induction temperature 142-146 deg. F. Maximum pressure: "A" bank 1,040lb. per sq. in. at 100 b.m.e.p.; "B" bank 1,025lb. per sq. in. at 100 b.m.e.p.

and the "Satco" metal had broken away from the steel shells.

(iii) It had been found impossible to get any cylinder head joint to last more than a few hours.

In view of the disadvantages it was decided not to proceed with the experiment. In many ways, from a technical viewpoint, this decision is to be regretted; but it must be remembered that in 1940 technical considerations were by no means the most weighty and, in many quarters, short term policies were of far greater importance than long range plans.

In the light of present knowledge, and indeed knowledge which was available in 1940 though not perhaps so widely disseminated, the cures for the major defects are fairly obvious:—

(i) Abandon the "monobloc" and "access door" scheme and go in for a carefully designed split crankcase, with controlled changes of section, and "pot" type steel cylinders with welded jackets—which would, incidentally, have eliminated (iii).

(ii) A balanced crankshaft would have helped a lot but it would probably have paid also to go to the extent of using a hard shaft and lead bronze bearings.

Wisdom after the event is reputedly easy; discernment of the causes of failure in a case such as this, over a considerable space of time and with a far from complete knowledge of events, is not easy. However, a study of the backgrounds of the three bodies comprising the design team responsible for the production of this engine enables certain conclusions to be drawn which, if not conclusive, are at least suggestive.

The Admiralty, as the customer, stated the requirements which, in their opinion, the engine must meet to give satisfactory service. In the nature of things they asked for more, in some respects, than they could reasonably hope to receive. Their demand for piston changing through access doors and for air starting on such a small engine made the problem far more difficult than was then realized and, in the light of subsequent developments, neither feature was necessary. Additionally, through the A.E.L., they offered advice on overcoming the various difficulties which arose; but it should be borne in mind that no one in the Admiralty had been previously concerned with the successful production of machinery of similar size and type. The advice offered had, therefore, to be extrapolation of experience gained from far larger and heavier machinery.

Messrs. Ricardo carried out the unit running and were responsible for the combustion arrangement and the basic plan for the multi-cylinder engine. The performance of the unit and the multi-cylinder engine showed the soundness of their contribution; but, here again, as far as the author knew, this was the first engine of this type made to their design and carried beyond the unit stage. Messrs. Davey, Paxman had to detail out the design so that it could be built with available plant by known methods. Their experience also rested on the production of machinery of very different specific weight.

It thus seems possible that, had either of these companies had a more extensive practical experience of the production of high-speed light-weight Diesel engines, the Admiralty's somewhat ambitious requirements might have been successfully resisted and the canons of successful aero-engine design, in respect to crankcase and cylinder construction, might have been accepted.

THE JUNKERS JUMO "205E" ENGINE
(SEE FIGS. 12, 13, PLATE 2, 14, PLATE 3, 15, 16, 17, PLATE 4, AND 18)

Cycle	Cylinders	Type
2	6 (in line)	Opposed piston
Cooling	Bore and stroke, in.	Max. h.p.
Liquid	4·13×6·3	600
B.m.e.p., lb. per sq. in.	R.p.m.	Piston speed, ft. per min.
106	2,200	2,310
H.p. per sq. in. piston area	Litres	H.p. per litre
3·725	16·62	36·1
Weight, lb.	Sp. wt., lb. per h.p.	
1,147	1·91	

The general shape and arrangement of this engine will be appreciated from the table above and the illustrations. The

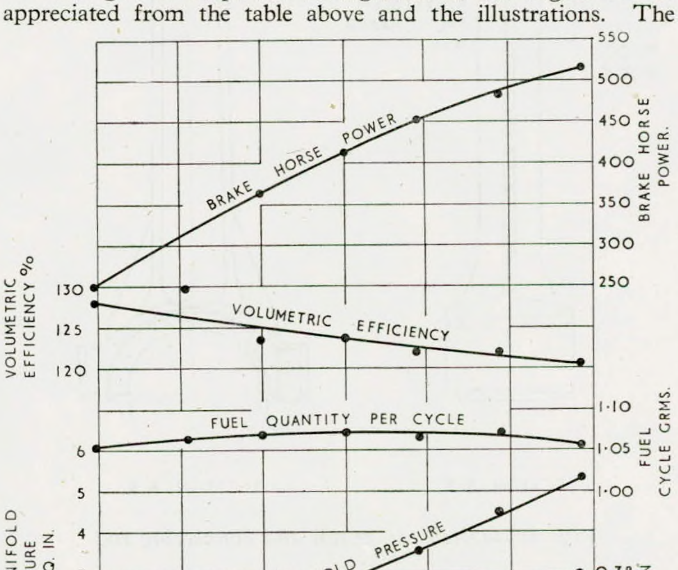


FIG. 15—*Performance curves of Junkers Jumo 205E engine*

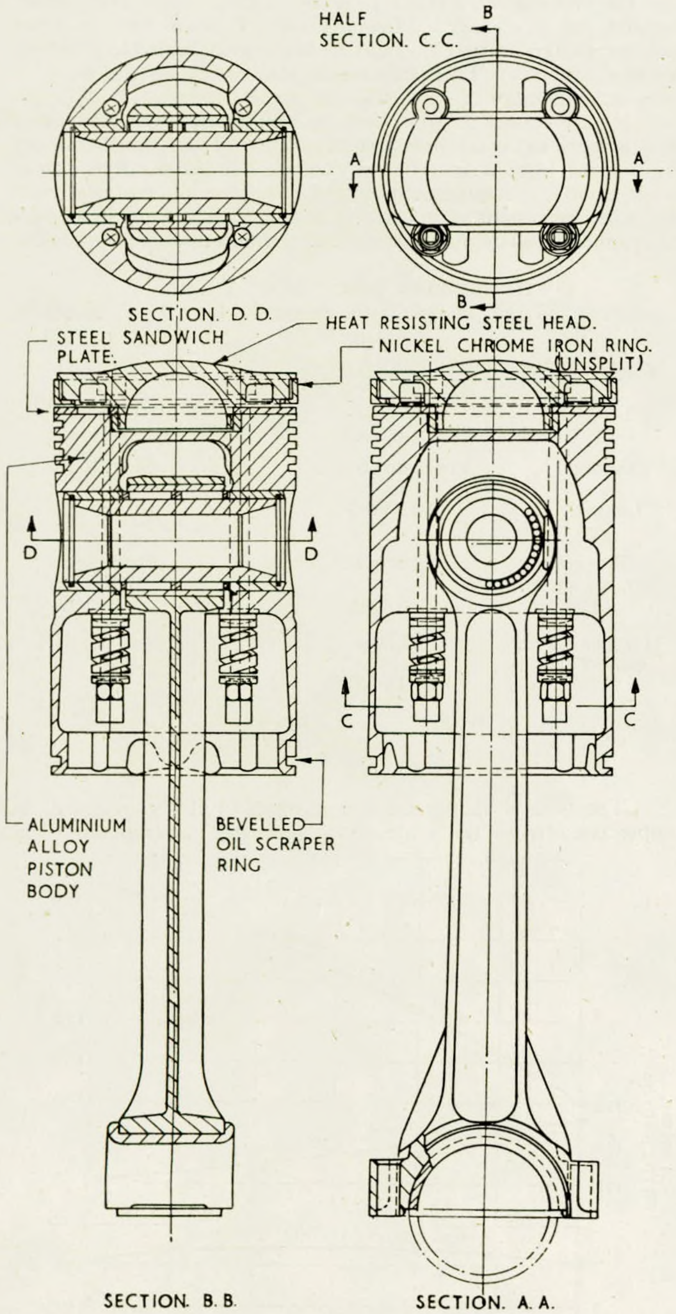


FIG. 18—*Details of piston and connecting rod*

figures were obtained from an engine built in 1941 or 1942 and subsequently tested in this country. It was, at this time, being used by the Germans in military transport aircraft.

The most remarkable things about the engine are, perhaps, its extremely low specific weight and low fuel consumption which, as far as the author is aware, are the lowest which has ever been achieved in a Diesel engine of comparable output. This result can only be attributed to a masterly choice of the principal dimensions of the engine, coupled with a long period of strenuous development in every detail.

The performance of the engine is highly satisfactory, as can be seen from the curves, and a continuous rating of 500 h.p. is high, judged by the standard obtaining in this class of machinery.

600 h.p. is very clearly the maximum power which can be expected from the engine in its present form, since at this power various significant events take place. First of all the exhaust begins to shade; an indication that combustion efficiency is on the wane. The air supply to the cylinders has been reduced to a minimum, 1·2 to 1·3 swept cylinder volumes per cycle, and by modifying the blower characteristic to increase this, it is possible that the range of satisfactory combustion might be extended to higher powers. Again, when the b.m.e.p. is raised to 106lb. per sq. in., cracks develop in the "corset" of the cylinder liner. These could possibly be avoided by modifying the liner sections or changing the material but, on the other hand, it is clear that the form of this component is the result of protracted empirical development since the stresses are not such as to lend themselves to mathematical analysis. It is therefore fairly certain that the desired improvement could not be successfully achieved without the expenditure of a great deal of development effort.

Although no trouble has been experienced with the piston or its rings when running on a lubricating oil with suitable chemical additions, it is quite clear that the thermal loading must be very near the realizable maximum for a two piece uncooled piston. This exceptional design is shown in Fig. 18.

This loading, expressed in terms of b.h.p. per unit of piston area is higher, the author thinks, than that of any other engine in serial production. It will thus be apparent that, if any serious attempt is to be made to increase the engine output, very careful consideration will have to be given to the problem of piston cooling which will almost certainly involve a complete re-design and development *ab initio*.

Examination of the parts of this engine makes it clear that a very large factor contributing to the outstanding performance is the care with which every single component has been designed and made to the lightest possible scantlings. Unlike the Mercedes Benz and the General Motors "Pancake", this engine is not an exhibition of technological virtuosity but a straightforward assembly which could be manufactured in any first class precision engineering shop; perhaps, for this very reason, it is a more rewarding design to study than very many others.

As far as the future is concerned, it would seem possible to deduce that there is a great future for development in the two-stroke opposed-piston engine. In its simplest form it presents no problems which are not common to all further advance—such as piston cooling—and in many ways it provides a more thoroughly explored and developed background than is available in many other types.

THE PERKINS "T12" ENGINE
(SEE FIGS. 19, 20 AND 21)

Cycle	Cylinders	Type
4	12 (55 deg. Vee)	Single acting trunk piston
Cooling	Bore and stroke, in.	Max. h.p.
Liquid	6×6	1,000 (a) 850 (b) supercharged
B.m.e.p., lb. per sq. in.	R.p.m.	Piston speed, ft. per min.
170 (a) 144 (b)	2,300	2,300
H.p. per sq. in. piston area	Litres	H.p. per litre
2·95 (a) 2·5 (b)	33·4	30 (a) 26 (b)
	Weight, lb.	Sp. wt., lb. per h.p.
	3,850	3·85 (a) 4·53 (b)

(a) As designed. (b) At present rating.

This design, in many ways quite first class, has been dogged by misfortune since its conception. However, it is of very considerable technical interest and the story of its development may, in certain respects, serve as a cautionary tale to those

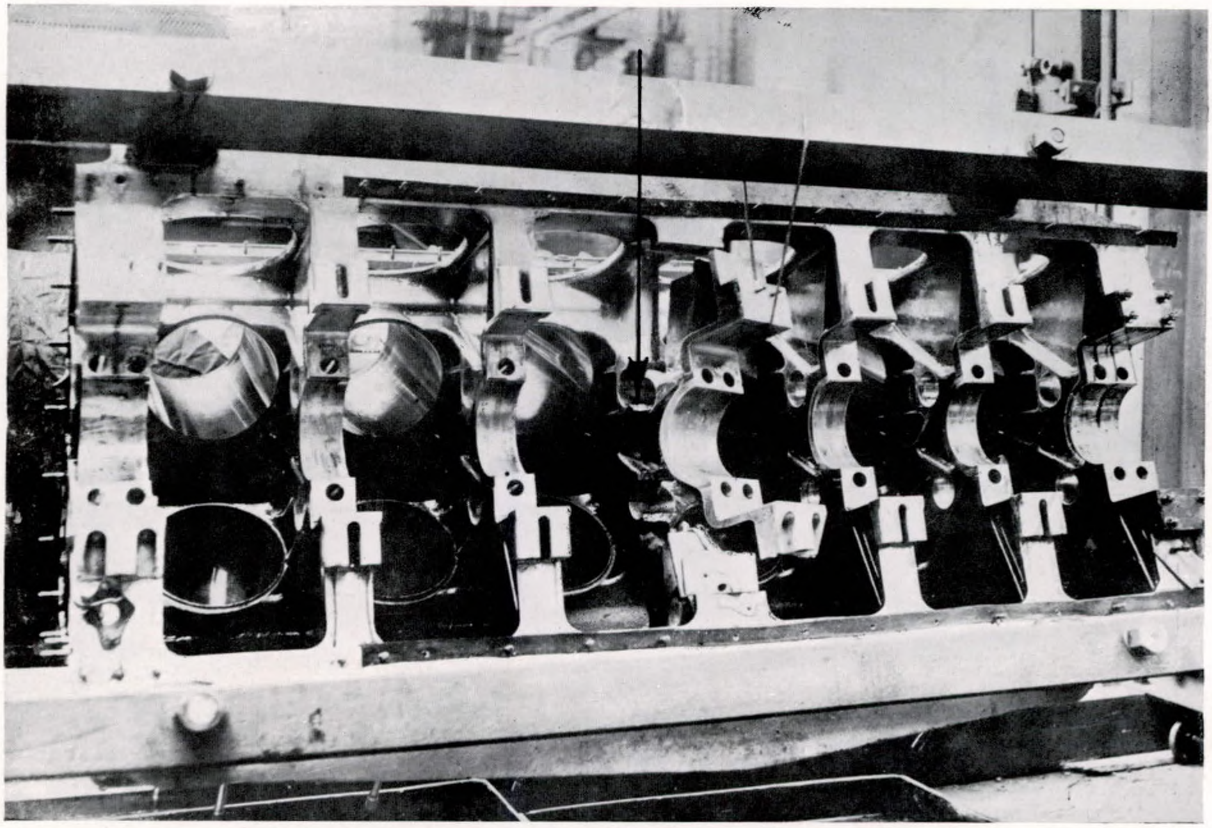


FIG. 10—*View of bottom of crankcase showing fracture at centre main bearing*

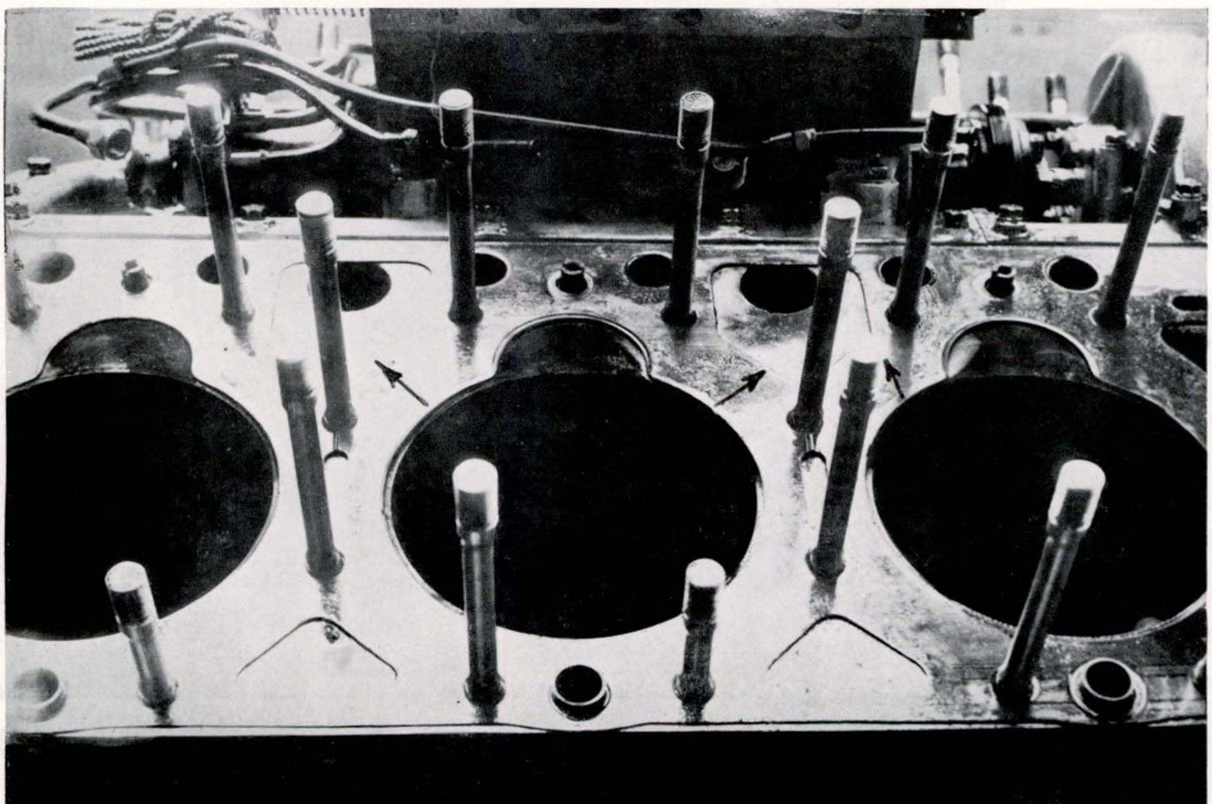


FIG. 11—*View of top of cylinders showing failed gasket*

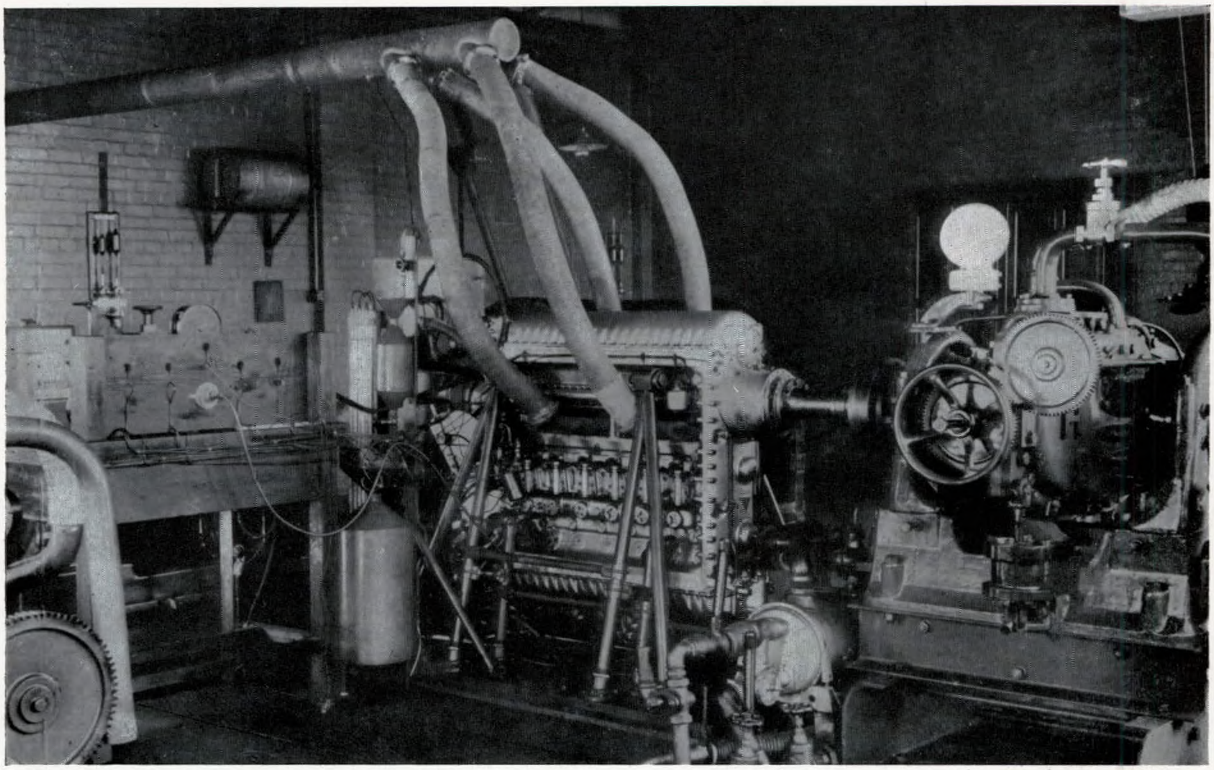


FIG. 12—*General view of engine on brake*

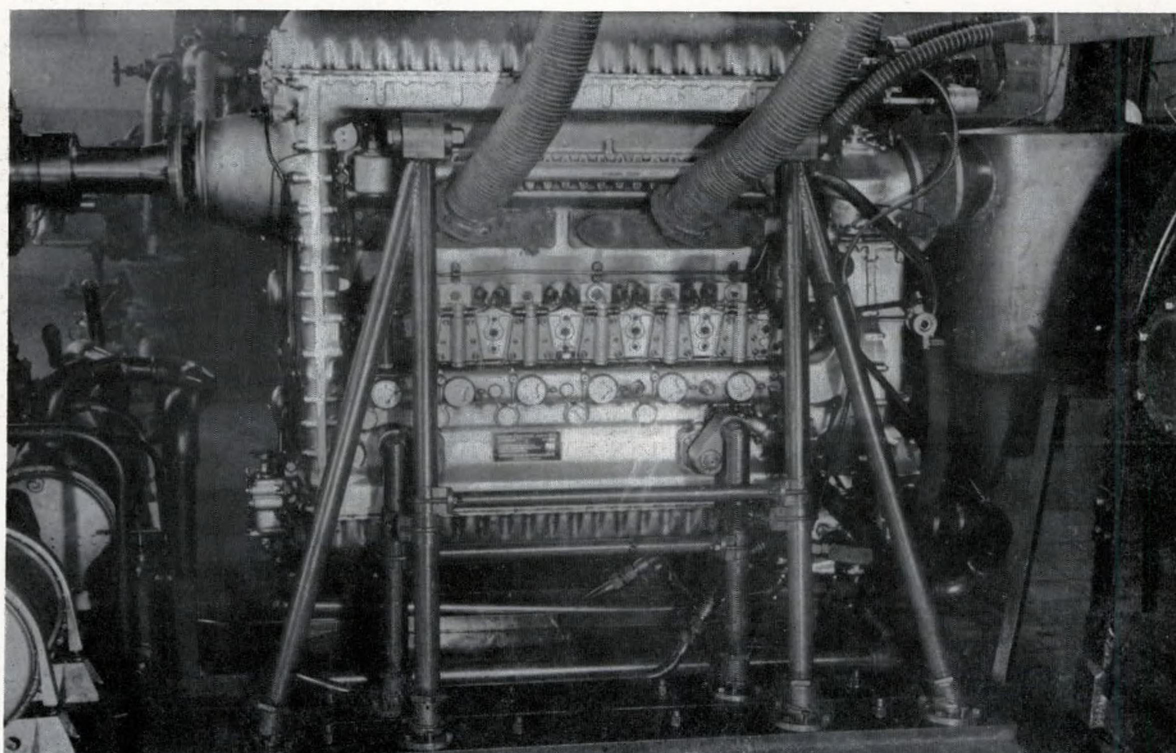


FIG. 13—*View of port side of engine*

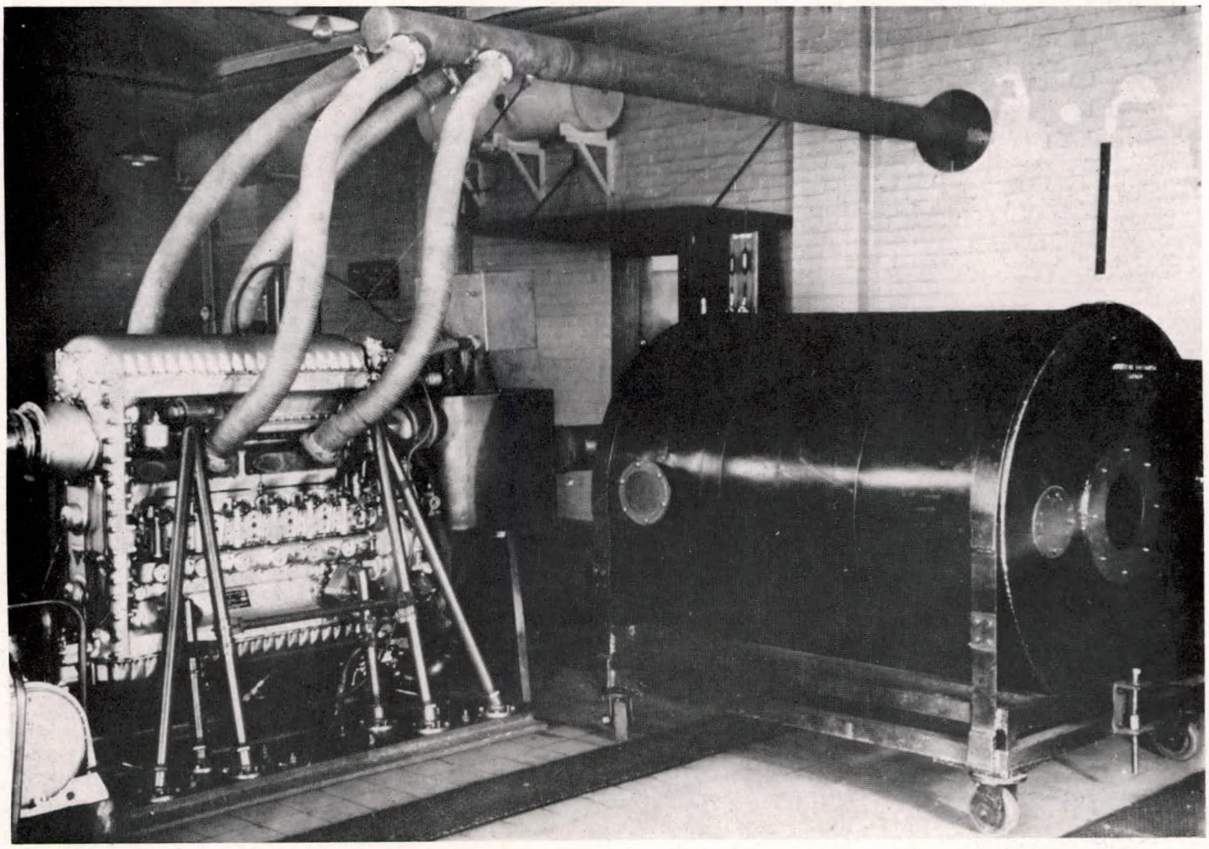


FIG. 14—*General view of engine showing air measuring tank*

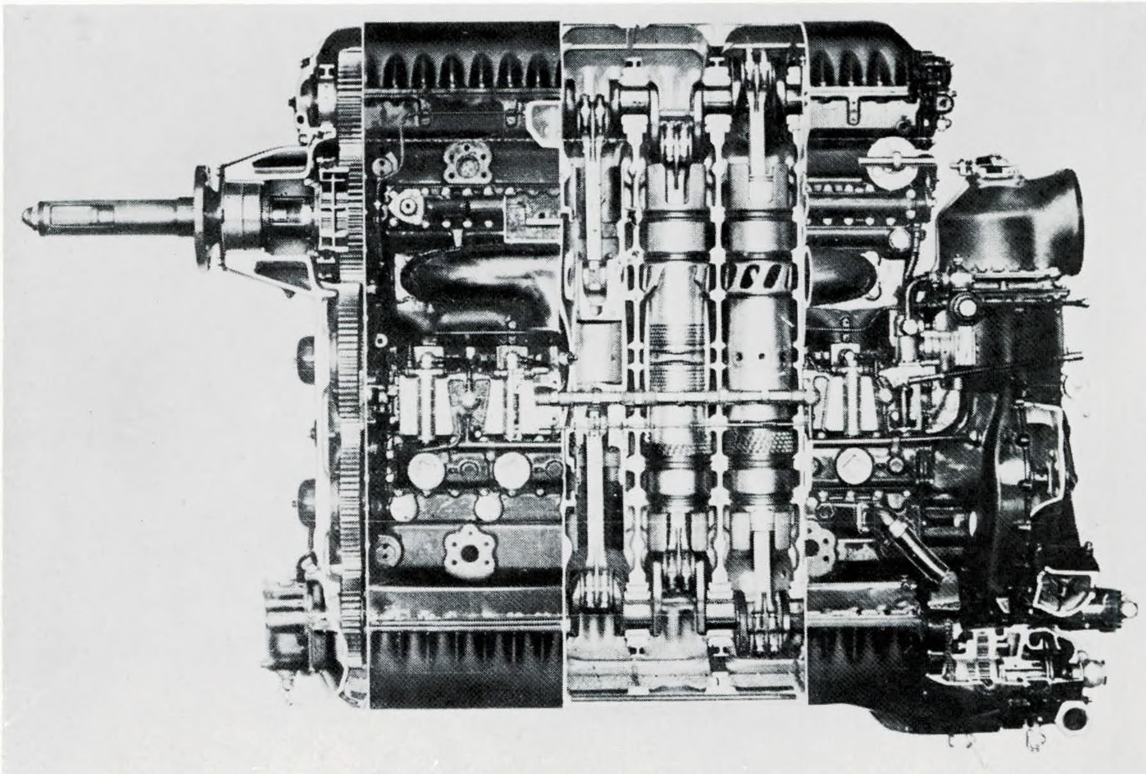


FIG. 16—*General view and part section*

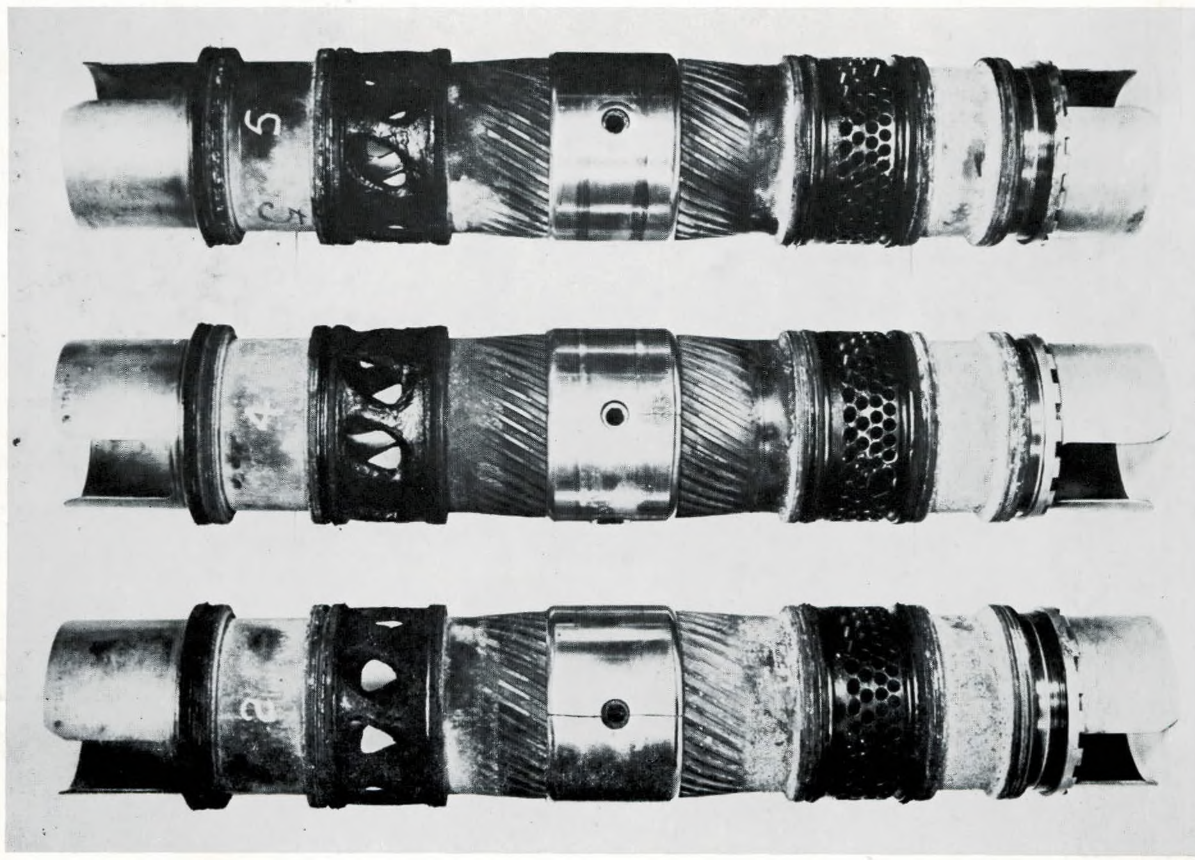


FIG. 17—*Cylinder liners showing corsets split after full power running*

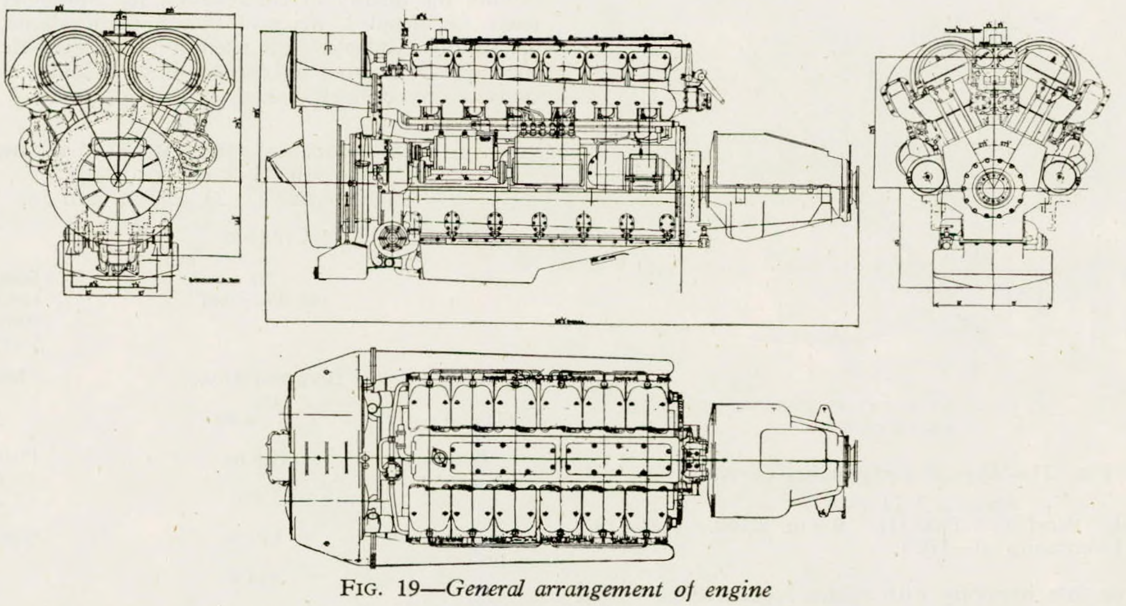


FIG. 19—*General arrangement of engine*

sufficiently intrepid to attempt the Herculean task of guiding the development of a highly rated Diesel engine from drawing board to production line.

The original work on the T12 was carried out by Messrs. Perkins of Peterborough to the order of the Ministry of Aircraft Production in the late 1930's. The engine was conceived to replace the Rolls-Royce Merlin which M.A.P. hoped to use in R.A.F. air-sea rescue craft. The author is not cognisant of the early history of the development and he can only start his account in 1941 when M.A.P. gave up the idea of using Diesel engines of this size for air-sea rescue purposes.

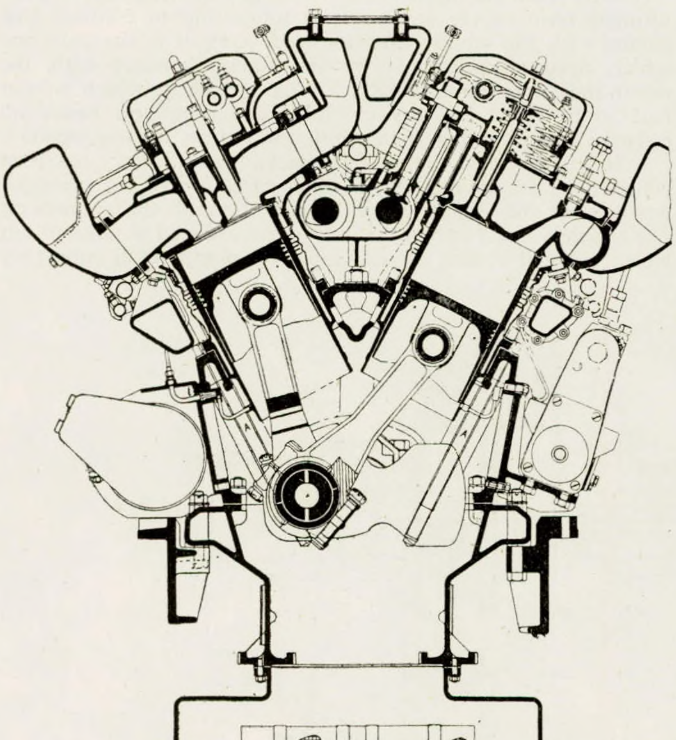


FIG. 20—*Arrangement of engine—transverse section*

By this time much running had been done on a unit engine, and one of the six twelve-cylinder engines had passed an Air Ministry type test. The Admiralty took on the development of the engine primarily with a view to fitting it in "B" type Fairmile M.Ls. instead of the 650 h.p. Hall Scott petrol engine. The Diesel offered the advantages of greater range, probably less maintenance, and a large reserve of power to maintain the speed of these craft whose displacement was being constantly increased as more weapons and equipment were added to the hull.

Looking back on events now, it seems fairly certain that the Admiralty did not appreciate the small amount of endurance running which had been carried out on the multi-cylinder engine for, after a short proving test at the Admiralty Engineering Laboratory, two engines were installed in a "B" type Fairmile. A good deal of trouble was experienced—not much more than normal teething troubles, really; but an experimental boat which is relying on an operational base for maintenance in wartime does not enjoy much priority, and every job took a long time to do. However, after about two years, the design had been modified quite considerably. The cooling system, except for the crankcase base and charge coolers, had been changed to use fresh water, the duplication of pumps, which formed part of the original design, had been eliminated and the drives simplified and modified. The exhaust system had been found unsatisfactory as persistant leaks at the manifold-cylinder joint impaired engine-room habitability. Lastly several crankshafts had been broken.

At this stage (1944) it was decided that further work in the boat was useless and that the only way to get results was to carry out a planned development programme at the Admiralty Engineering Laboratory. Accordingly, the boat installation was dismantled and work started at the Admiralty Engineering Laboratory. The programme proceeded at varying priorities until 1947 when it was finally decided that an engine of this size and type was unlikely to be needed for naval purposes.

During these three years quite a lot of work was done. The crankshaft breakages were not easy to pin down to a specific cause; the design was skinny, of course, but there were also rather small journal fillets and numerous non-metallic inclusions in the shafts which failed. However, it was decided to increase the crankpin diameter by $\frac{1}{8}$ inch and re-design the big ends and no trouble has ensued with the modified shafts.

The breathing of the engine was carefully checked and much better volumetric efficiencies were obtained by modifying the supercharger diffuser passages so that the supercharge characteristic was stabilized further from the surging line and

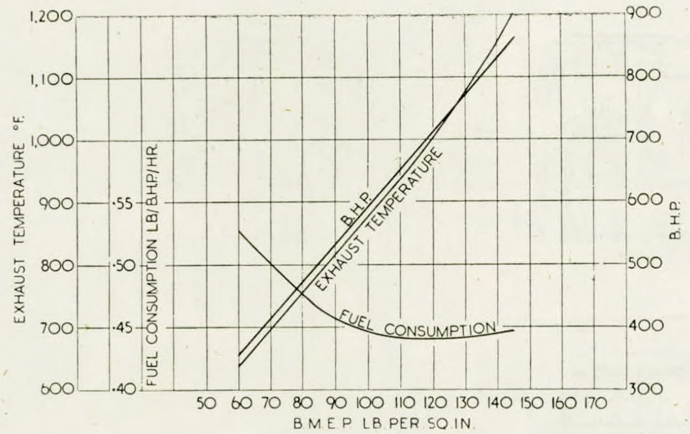


FIG. 21—*Typical performance curves*

PERKINS T.12 ENGINE

Supercharged. Boost 15·8 inch Hg. R.p.m. 2,300. Fuel—Pool Diesel oil. Lubricating oil—HD30.

brought more into harmony with engine requirements. Some work remained to be done to improve equality of distribution among cylinders, as combustion was appreciably inferior to that of the single- and the twin-cylinder units.

It is of interest to note that a modification to the top of the combustion recess, carried out purely to afford a measure of stress relief to the cylinder head casting, was instrumental in producing a considerable gain in combustion efficiency on the unit engine.

Considering the design as a whole, one is impressed by the good results achieved by the policy of "moderation in all things" which it reflects. Despite the high b.m.e.p. and fairly high power loading on the piston, neither this component nor its rings gave any real trouble. In fact one could state fairly that, in the condition in which the engine was left, it only needed a comparatively small amount of further development work to become a reasonably satisfactory prototype within the parameter of its design.

Two lessons, perhaps, stand out most clearly from experience with this engine. The first was that such designs should be kept as simple as possible. Troubles were greatly reduced upon the removal of the complication of dual pumps and systems. The second lesson was that development of such engines must be carried out extensively on a shore test bed where the whole battery of analytical instruments for determining the quality of combustion, the durability of wearing parts, the detailed effects of minor modifications, and so on, are readily available. To attempt to discover the answers to such questions from an engine running under service conditions is very difficult indeed, if not impossible.

THE MERCEDES BENZ "M.B.511" ENGINE
(THE "E-BOAT" ENGINE)
(SEE FIGS. 22, 23, 24, 25 AND 26)

Cycle	Cylinders	Type
4	20 (40 deg. Vee)	Single acting reversible trunk piston supercharged
Cooling	**Bore and stroke, in.**	**Max. h.p.**
Liquid	7·28 × 9·84	2,500
B.m.e.p., lb. per sq. in.	**R.p.m.**	**Piston speed ft. per min.**
146	1,650	2,750
H.p. per sq. in. piston area	**Litres**	**H.p. per litre**
3·0	134·4	18·6
Weight, lb.	**Sp. wt., lb. per h.p.**	
10,400	4·2	

From the actual engine, if not from the above details and the illustrations, one gains the impression of a very refined design in which every detail has been patiently developed over a period of years and in which no artifice of technique is not employed to achieve the desired end.

This is the engine the Germans fitted in the E-Boats. It had its forbears in the machinery produced for Dr. Eckener's Zeppelins and for that phenomenal train the Berlin-Hamburg flier. By 1940 the design was virtually stabilized as the penultimate term of the series. It is interesting to contrast this engine with the others here discussed, since it is the only one which departs radically from the square concept with the result that it is dimensionally a large engine in which weight had to be saved by very carefully designing and balancing essential masses rather than eliminating them by compression.

It will be noted that a high mechanical efficiency has been achieved by employing ball or roller races for all the principal bearings in the engine with the exception of the connecting rod bearings and, further, that oil drag is reduced to a minimum by an unusual system of individual oil pumps each supplying

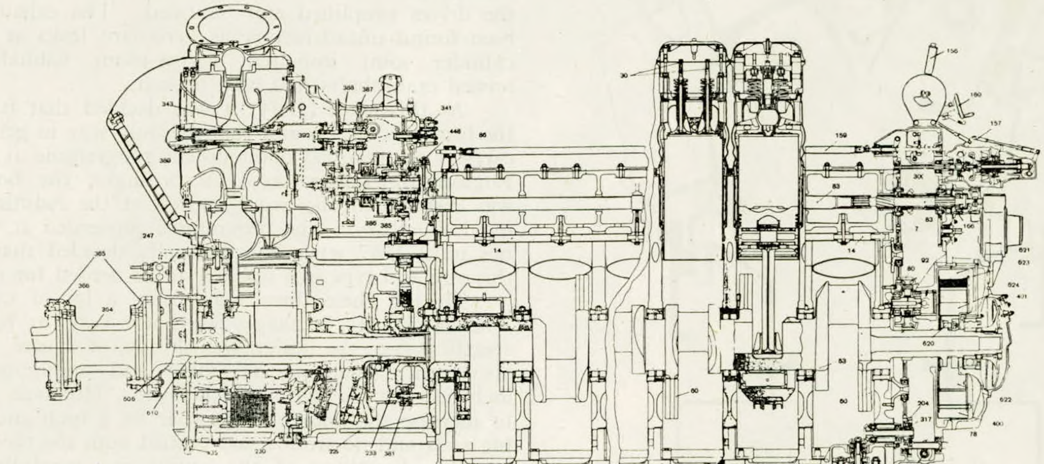


FIG. 22—*General arrangement—longitudinal section*

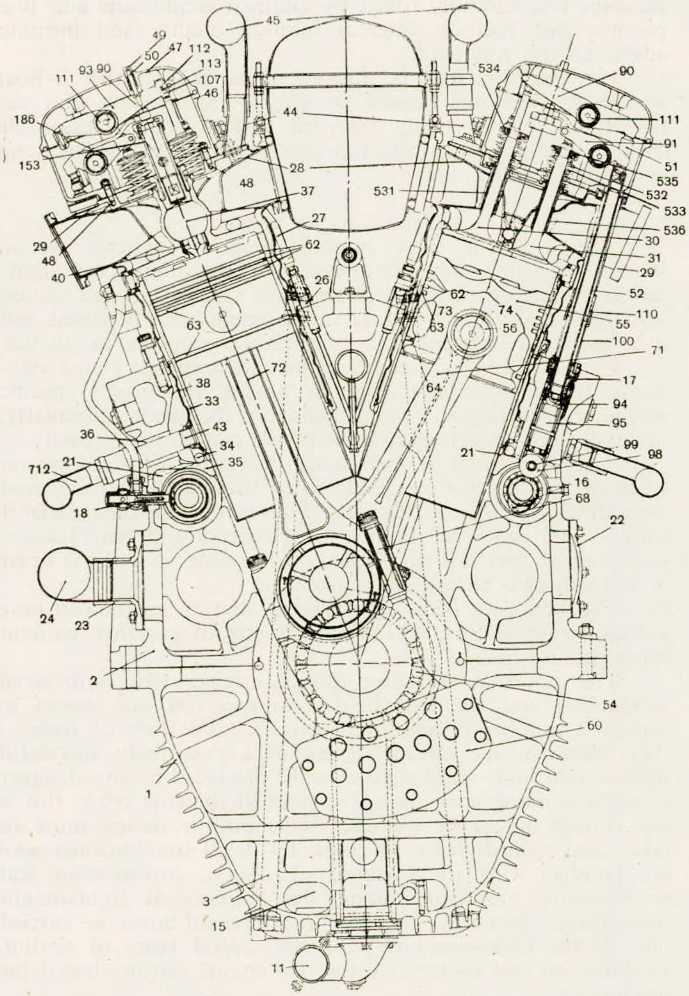


FIG. 23—*General arrangement—transverse section*

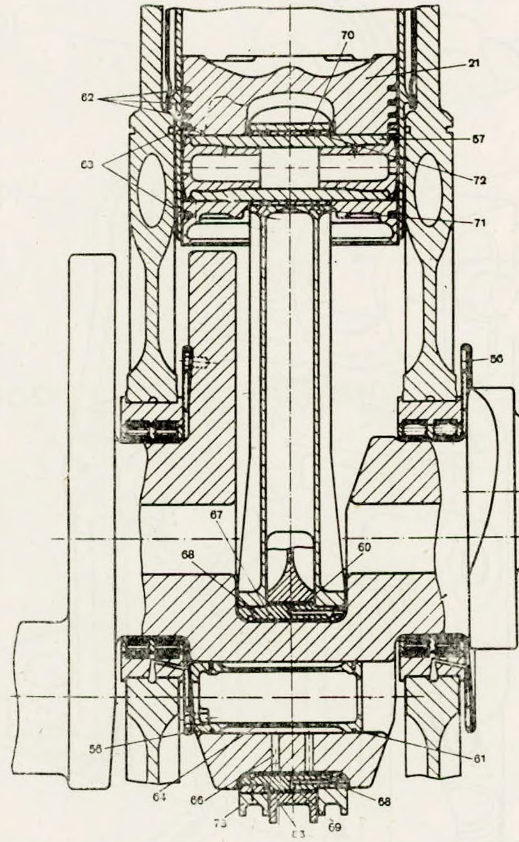


FIG. 25—*Piston, connecting rod, roller main bearings, etc.*

The piston (21) is a light alloy stamping; the gudgeon pin (57) is fully floating and fitted with end locating plugs.

The forked connecting rod (73) runs on a lead-bronze bearing (68) while the centre rod (86) runs of a lead-bronze bearing (69) on the forked rod steel bearing shell (67).

A metering pump, Fig. 26—one for each main bearing excepting the foremost bearing, supplies lubricating oil to the main bearing by way of a vertical duct in the bearing girder and nozzle shaped ports in the outer roller race. Oil is also led to the inside of thrower ring (56) and from there is conducted to the connecting rod large end bearing through the hollow crankpin.

The small end bearing is splash lubricated through holes (72).

a metered quantity of oil to each main bearing. There is no known history of bearing failures so it must be assumed that this piece of unorthodoxy was successful.

MERCEDES-BENZ TYPE 511
Engine inclined at 5 deg. from horizonal.
Exhaust shades.

r.p.m.	50	60	70	80	90	100	110	120	130	140	150
1,200 — —	c	c	c	c	c	ss	ss				
1,400 — ·		c/ss	c/ss	c/ss	c	c	ss	ss			
1,500 ——		c/ss	c/ss	c/ss	c/ss	c/ss	ss	ss			Q
1,630 — —				c/ss	c/ss	c/ss	ss	ss	s/ss	s	s/o

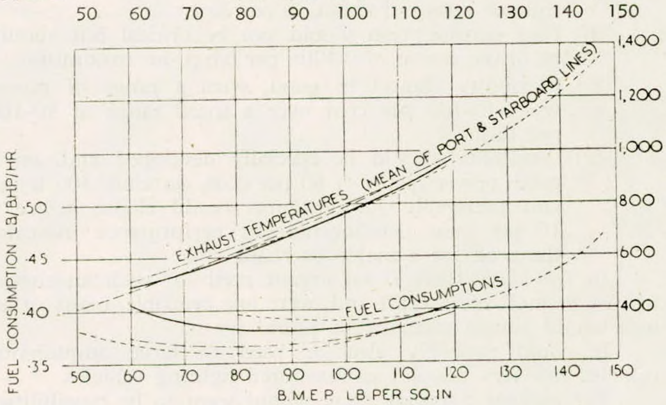


FIG. 24—*Performance curves*

The careful valve arrangement and smooth porting suggest easy breathing and volumetric efficiency is enhanced by the use of a charge cooler in the supercharger trunking thus passing the heat of compression on to the sea water system.

The large size and light weight of the engine have made it essential to keep thermal stresses caused by temperature differences to a minimum and provision was made for warming the whole engine by cross-connecting its cooling system with that of an auxiliary engine before starting up.

Time and again, in studying this design, one comes back to the question of weights; how was such a large engine made to be so light? Apart from an extraordinarily well balanced design, one's attention is held by such examples of production virtuosity as the cylinder head fabrication and the crankcase casting.

It is not easy to give a conclusive picture of the performance of these engines. Prisoners of war, as a rule, spoke highly of the degree of reliability attained but said that a lot of maintenance was needed; a top overhaul at 350 hours and return to the works at 600 hours, which is what one might expect.

An engine was run at Admiralty Engineering Laboratory, West Drayton, and combustion conditions indicated that the quoted rating was suitable for extreme emergency use only.

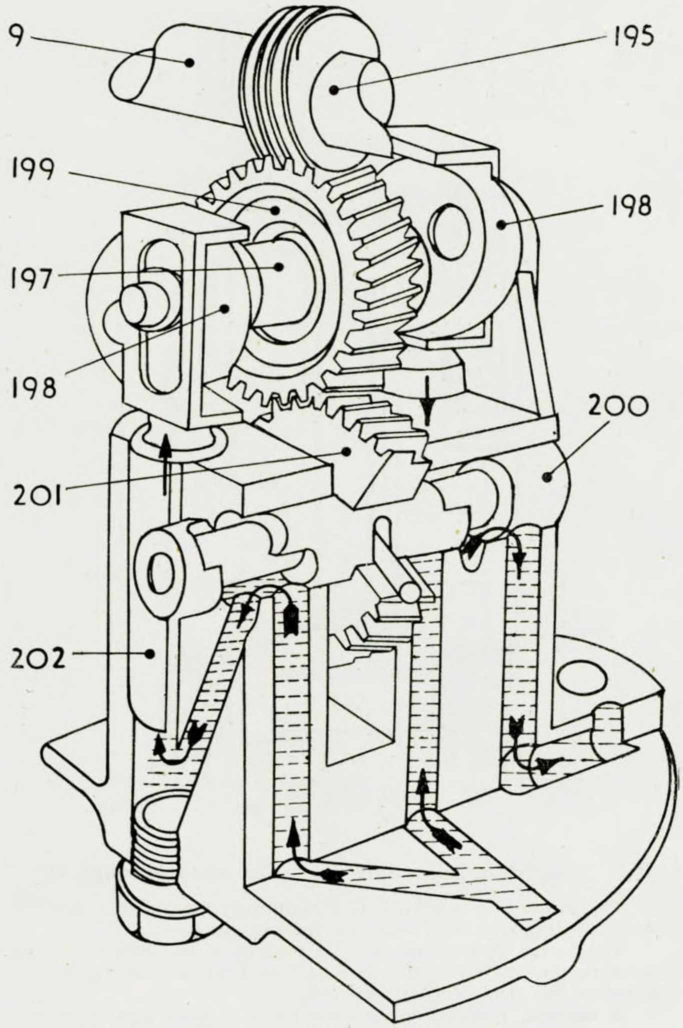


FIG. 26—*Bearing lubricating oil metering pump*

A metering pump is fitted under each of ten of the main bearings the foremost bearing being supplied with oil from above the bearing—see Fig. 22.

Each pump has two plungers driven by worm (195) on shaft (9). The driving wheel (199) on shaft (197) is situated between two plunger operating cams (198) phased at 180 deg. The second wheel (201) drives the rotary valve (200) controlling the suction and delivery ports. To provide for reversed rotation, wheel (201) carries a pin which engages with a slot in the rotary valve (200) giving 180 deg. lost motion during reversal.

The metering pumps take suction from the delivery line of the main lubricating oil pump. The delivery and scavenge pumps are of the gear type and are contained in a common housing (318), Fig. 22; these pumps are driven by a double gear arrangement fitted with free-wheel devices to provide for reverse rotation.

The metering pump shaft (9) is splined into wheel (317) Fig. 22 but shaft (9) is not shown in that Fig.

Even when running at the maximum continuous rating, piston failures were encountered.

In America, however, reports suggested that the engine was quite happy up to and above its rated power, and gave no trouble at all. This disparity in results can perhaps be reconciled by realizing that the combustion system in this engine is clearly one of great delicacy and that any departure from the designed condition in either the sequence of valve events or the fuel quality might well be sufficient to cause disaster. The engine at the Admiralty Engineering Laboratory was run as received from Germany and Standard Admiralty Diesel fuel was used. It is understood that the engine in America was carefully tuned by German technicians and it is possible that fuel of different ignition quality and burning characteristics was used.

However that may be, history makes it clear that E-Boat availability was not limited by engine maintenance and the power unit was certainly regarded with a certain reasonable envy by our petrol propelled coastal force sailors for five long and exciting years.

LESSONS TO BE LEARNT

The study of these engines seems to indicate certain lessons regarding the development of the high-speed light-weight engine up to date. From them can be inferred certain principles upon which future developments can be based and it is such developments that the author proposes to discuss.

First of all, it is quite clear that the opposed piston two-stroke has a great advantage in having the lowest specific weight and the highest power loading on the piston. Similarly, this type shows the largest horse-power per litre of capacity.

Regarding speed of operation, it can be noted that a piston speed of 2,750ft. per min. (Mercedes Benz) has been achieved without ill effects; that General Motors operate their exhaust valves 1,800 times per minute with success and that Junkers injects and burns fuel in 1/8,800 of a minute (i.e., of the order of 1/140th of a second) satisfactorily.

The Mercedez Benz demonstrates that an engine can have a large swept volume and a modest output per litre without being unduly heavy.

The fact that the three foreign engines went into serial production and the two British engines did not, seems to signify a number of important points. The first of these is that, although the outline design of a potentially successful light-weight high-speed engine can be produced by any designer of merit working with the aid of a small drawing office, this is not enough to secure success. This outline design must be taken and refined, piece by piece, by detail draughtsmen who are familiar with the methods of design, construction and manufacture prevalent among the builders of light-weight machinery. Secondly, the final development must be carried out on the brake—and it will take several years of testing, modification and re-design before the engine can be cleared for production.

The variety of the engines produced all to meet a more or less common requirement is, the author considers, interesting as indicating that the Diesel engine is still a long way from the ultimate stage in its development. As a contrast, note the unanimity with which the sleeve valve mechanism has been adopted by aircraft engine manufacturers for the ultimate term in the serial development of the piston engine for aircraft use.

PLANS FOR THE FUTURE

The author believes that there is a substantial demand for an engine conforming to the following broad specifications:—

(i) Specific weight, not more than 3·5lb. per h.p.

(ii) Maximum power not less than 2,000 h.p. with a continuous rating of about 70 per cent.

(iii) Fuel consumption would not be critical but should be in the region of 0·40lb. per b.h.p.-hr. maximum.

(iv) Flexibility should be good, with a range of power from 10-100 per cent over a speed range of 30-100 per cent.

(v) Durability should be specially developed and, on a mean power factor of 60 per cent, certainly 500 hours and preferably 1,000 hours should elapse before a 10 per cent deterioration in performance indicates the need for a major overhaul.

In the Navy there is an urgent need for such an engine for use in high-speed craft and, were one available, many other uses would almost certainly be found for it.

It could probably also be used in large amphibious vehicles and very possibly in armoured fighting vehicles.

For civilian purposes there would seem to be possibilities of its use in high-speed rail cars where there seems to be great scope for reducing the ratio of vehicle tons per passenger. It would also be an ideal unit for high-speed customs launches and aircraft tenders where instant availability and avoidance of stand-by charges are important.

As a light compact unit, readily transportable by air, it would be supreme. There is little doubt that a stock of such units will soon be built up in every major nation to supply mobile power for dealing with the catastrophic effects of earthquake, typhoons, flood and fire. It would be interesting to compute the effect of, say, 100 such units on the Fenland floods of 1947.

With these potential uses as a spur to the imagination, it may not be thought unreasonable to review the possibilities of getting out the design for such an engine.

DESIGN CONSIDERATIONS

A few of the major design considerations will be briefly discussed before an attempt is made to outline a possible design to meet the requirements stated in the previous section.

On the available evidence, the choice inevitably rests with the two-stroke engine. This cycle keeps the mechanical stresses lower for a given output and, in turn, permits a lighter structure for the engine itself. A more even turning moment is provided which reduces the flywheel requirement and simplifies the problems of balance and torsional vibration. Usually, a smaller cylinder size can be employed than with a four-stroke which again makes for a lighter engine. There are thus a variety of sound theoretical reasons why the two-stroke cycle should be chosen.

There are, of course, drawbacks. The breathing and scavenging are more difficult since inhalation and exhalation take place at double the rate of a corresponding four-stroke engine.

The thermal loading, particularly of the piston, is higher since more fuel is burnt per unit of time.

The design of the little end bearing in a two-stroke also produces some awkward problems of mechanical design since it is subjected to a fairly constant downward loading combined with a very restricted amount of oscillation. Nonetheless, several reasonably elegant solutions have been evolved which will probably permit the cycle pressures to be taken as high as other features of the mechanism at present allow.

It will be probable that the lightness and compactness attained by use of the two-stroke cycle will be offset by a lower fuel economy since there will be a higher back work dedendum to provide artificial respiration.

Securing satisfactory combustion in any design will be fundamentally a problem in kinematics to ensure that the organization of the air movement in the cylinder in relation to the spray pattern is such that the hydro-carbon particles are continually fed with oxygen from the moment combustion is initiated. With shortening combustion periods this process has to be even more carefully arranged to avoid excessive rates of pressure rise and to ensure that all the fuel is oxidized before the exhaust phase begins. Although there are various well-established methods of bringing this about, it must be admitted that all are subject to final amendment by practical trial which, in the hands of a skilled development engineer, will produce results far beyond what can be accomplished by calculation and paper design.

Although it has been seen in the Mercedes Benz, that it is possible to build an engine of large dimensions and modest power/volume ratios and still preserve a satisfactory specific weight, it is not unfair to state, as a generalization, that a small, highly rated engine is likely to be the lighter. It can be said that increasing the rating will decrease the reliability; but this is not inevitable since, in the small engine, devices can be employed to increase load carrying ability—surface finish, metallurgical processing, dimensional precision—which cannot be so readily applied to the dimensionally larger engine. There are also very many production advantages, in the present state of the industry, to be gained by keeping the cylinder diameter below 7 inch.

A number of factors influence the geometry of the engine. It must be the aim to keep crankshafts short and stiff to simplify torsional problems and to resist bending stresses. Similarly, the shorter the engine the lighter can be the framing from the viewpoint of beam strength. In some applications accessibility for repairs and adjustments in place is important; in others, a maximum block coefficient to secure economy of space is what matters. The latter consideration applies to this case so that it will be seen that an "H" type engine must appear in a very favourable light.

The success or failure of the design will, in the last analysis, depend on the mechanical details of construction. This is anathema to many designers since the art has now become so specialized that few designers dare stipulate very closely how the engine is to be built. But engine building firms have acquired by now their own particular ways for solving various mechanical problems and it will be a rash man who will dictate to such people how to set about a particular task in the first place. It is, perhaps, labouring the point to say that any method of construction which allows an engine to accomplish its designed performance and durability is the right method to use.

Thus, a basic design handled by two different firms, in two different countries, would probably produce two engines different in every detail; but if both firms were of equal merit and had access to similar resources there should be little to choose between the engines.

Thus, the author would not attempt to support welded steel frames against cast aluminium clothing a skeleton of bolts, nor rolling bearing against copper-lead, but he would leave the choice in such matters to the man who is to build the engine, in the knowledge that what can be handled satisfactorily by one firm may give endless trouble in another.

There are, however, limits to this liberal policy. One is the exclusion of rare materials. It is unsound to build an engine intended for world-wide use in peace and war which requires for its manufacture and maintenance some such special material as an alloy whose constituents have a strictly limited source of supply; one cannot afford to have production and maintenance prevented by either political or commercial unilateral action. The other is the avoidance of complexity. In the first place, to secure the reliability which is essential in a complex mechanism, a great deal of development and production time will be needed; in the second place, simplicity is the stamp of genius. While one may not aspire to such heights there should be a certain standard of mechanical elegance below which one tries not to fall. When the intrusion of some complexity seems inevitable the question can sometimes be resolved by considering whether the price of its inclusion is or is not higher than that likely to be paid for abuse caused by occasional human ineptitude if it is omitted.

PROJECT A

Table 1 shows the leading particulars of an outline design designated "Project A", together with the same particulars for the engines discussed earlier in the paper.

This very sketchy outline is not put forward in any way as a panacea engine or as an exclusive design; it is merely an endeavour to show that the target outlined earlier in the paper could come well within one's grasp at the price of a comparatively modest development programme.

The two-stroke cycle has been chosen because the emphasis in the requirements is firmly on light weight rather than on economy and, as discussed in an earlier section, the two-stroke has a marked advantage here.

The "H" type engine is chosen as showing up well on the basis of specific volume when building an engine comprising a large number of small cylinders. The 6-inch bore cylinder is regarded to be of prime importance and twenty-eight of these are needed to provide an ample margin in the target power without going to extreme pressures or fuel rates. This is perhaps fortunate for the seven-crank two-stroke engines with opposed cylinders permits a number of satisfactory crank

TABLE 1. LEADING PARTICULARS OF ENGINES REVIEWED

Make	Cycle	No. of cylinders	Type	Cooling	Bore and stroke, in.	Max. h.p.	B.m.e.p. at max. h.p.	R.p.m.	Piston speed ft. per min.	H.p. per sq. in. of piston	Litres and h.p. per litre	Weight and sp. wt.
G.M. 16/184A	2	16 (4 banks of 4)	Single acting trunk piston through scavenge	Liquid open circuit	6×6¼	1,200	90	1,800	1,950	2·65	46·4 25·9	4,902 lb. 4·1
Paxman Ricardo	4	12 (60 deg. Vee)	Single acting trunk piston	Liquid open circuit	7×7¾	1,000	126	1,750	2,260	2·16	58·6 17·5	3,850 lb. 3·85
Junkers Jumo 205E	2	6 (in line)	Opposed piston	Liquid open circuit	4·13×6·3	600	106	2,200	2,310	3·725	16·62 36·1	1,147 lb. 1·91
Perkins T.12	4	12 (55 deg. Vee)	Single acting trunk piston	Liquid open circuit	6×6	1,000 (Designed)	170	2,300	2,300	2·95	33·4 30·0	3,850 lb. 3·85
Mercedes-Benz 511	4	20 (40 deg. Vee)	Single acting trunk piston	Liquid open circuit	7·28×9·84	2,500	146	1,650	2,750	3·0	134·4 18·6	10,400 lb. 4·2
Project A	2	28 (in " H ")	Single acting trunk piston through scavenge	Liquid in pressure circuit	6×6	3,200	110	2,400	2,400	4·0	78·0 41·0	9,600 lb. 3·0

arrangements which avoid torsional oscillations of undesirable magnitude. There will be no odd or half orders and, by choosing a suitable firing order, there need be no significant vibration until the second order whose frequency will be above the normal running range.

It is considered important to keep the bore down to six inches for a variety of reasons. Perhaps the most important is that there is a very considerable background of experience of Diesel engine running on this size of cylinder, both on units and multi-cylinder engines, and it is well not to attempt to break entirely new ground in too many directions simultaneously if development is not to be unduly protracted. Secondly, the manufacturing techniques for producing parts of reciprocating engines of not more than this size have been brought to a very high state of perfection in this country in the course of aircraft engine production; the achievement of a very close degree of geometrical precision is essential for the success of any highly rated machine and cannot be secured unless the great variety of complex production problems involved have been studied and solved.

The stroke of 6 inch has been somewhat arbitrarily chosen to give a reasonable piston speed and crankshaft speed. Opinions seem to be held variously on the merits of bore/stroke ratios though it is generally conceded that the "square" engine is the best for lightness and compactness while, on the other hand, the longer stroke will promote improved economy and facilitate the solution of overhead valve problems in the four-stroke engine. The author would not be surprised to find that, in the course of development running, it appeared that advantages could be gained by increasing the stroke to 6½ or even 6¾ inch. It is not uncommon to find that such a dimension is not decided by reference to the theoretical ideal but by the compulsion of some combination of practical details.

The b.m.e.p. and thermal loading of the pistons are both above what has so far been accomplished but not by an unreasonable margin. When one remembers that brake mean pressures of nearly three times this figure were carried in petrol engines, under full throttle conditions, it does not appear so startling. It is understood also, that in the revision which the General Motors 16/184A is at present undergoing the b.m.e.p. has been raised to 110lb. per sq. in. The figure of 4 h.p. per sq. in. piston area will call for great care in designing the piston which will probably have to be cooled by oil jet and "shake"; the high speed of reciprocation should make this method of cooling thoroughly effective. When the Jumo's 3·725 h.p. per sq. in. for an uncooled piston is recalled, 4 h.p. per sq. in. does not sound too ambitious.

However, in view of this and other dynamic features of the engine, it would seem that special care will have to be devoted to the lubricating-cum-cooling oil system. It is possible that a high circulation factor, a small temperature rise and a low viscosity oil will be found to give the best results.

Piston speed is on the high side but, again, is not a ceiling figure nor does it represent an unreasonable advance over known achievement.

The through-scavenge engine was chosen, after much heart-searching, as being the form most likely to achieve success with a minimum of development because all the features had an extensive background in both Diesel and petrol engine work. The opposed piston engine was carefully considered but, in these sizes and speeds, the British background was nebulous and it seemed fairly certain that difficult problems of combustion, breathing and dynamic loading would present themselves. A sleeve valve arrangement would probably provide even better volumetric efficiencies than the arrangement selected but it is, perhaps, sufficiently significant to note that sleeves enjoy a very limited popularity among Diesel designers. The difficulty with the through-scavenge engine will, of course, be the satisfactory and reliable operation of the valve gear 2,400 times per minute. Four valves would probably be used—six would complicate the head casting too much—and a fairly high lift/diameter ratio could be used to keep weight down. With a 6-inch bore, and having recourse to that fund of knowledge which developed the high-speed aircraft and automobile engine, it is not considered that the development of the valve gear need hold up progress for long.

The figure for weight is, perhaps, more a pious hope than the result of any comprehensive design calculations but, looking at the figures for the Jumo and considering the weight which could be saved on, say, the Perkins, it seems quite feasible.

The temptation now presents itself to plunge into detail design considerations regarding Project A; to make a case for roller bearing big ends and main bearings, to discuss the design of the valve actuating gear, and so on, but this, the author feels, must be resisted since such matters can only be viewed in their proper perspective when seen from the viewpoint of the firm undertaking the detailed design and construction of the engine. As has already been stressed, on a project of this sort it will be essential to employ known methods and known techniques even at the price of a sacrifice of some theoretically attainable efficiency. The development of new techniques is a matter which is best carried out as a long term development except when dictated by the failure of known methods to secure the desired end.

In conclusion, the author would again emphasize that Project A was not an exclusive design: rather did it follow in the wake of a number of proposals made by others, more illustrious and far better versed in the art than he.

In 1944, a committee under the chairmanship of Sir Roy Fedden recommended to the Admiralty as a solution to this problem, a 32-cylinder "H" type two-stroke engine with open ended sleeve valves.

In 1946, Messrs. Ricardo laid before the Admiralty proposals for a 32-cylinder "H" type four-stroke engine with overhead valves, and a family of through-scavenge "H" type two-cycle engines having 32, 40, 48 or 56 cylinders covering a power range from 2,800 to 4,900 b.h.p.

It will thus be seen that Project A is but one variation on a theme which has already been clearly stated, but it is thought worthwhile putting it forward afresh in the hope that it will re-focus attention on a basic design possessing very considerable development potentialities.

ACKNOWLEDGMENTS

The author's very grateful thanks are extended to Mr. C. C. Jeves, Principal Scientific Officer, R.N.S.S., and those members of his Technical and Clerical Staff at the Admiralty Engineering Laboratory, without whose very willing and able help, this paper could not have been compiled.

The paper is published with the approval of the Lords Commissioners of the Admiralty, but the responsibility for any statements of fact, or any opinions expressed rests solely with the author.

Discussion

MR. J. F. ALCOCK said Commander Middleton had taken as his theme a very specialized type of Diesel and had given a very thorough and critical review of the present state of the art, though he could not quite agree with his first sentence in which he said that the Diesel engine designer had been absorbed for the last twenty-five years in developing the aero-engine. The vast majority of them were developing road-vehicle engines and did not bother their heads in the least about aero-engines. Naturally Commander Middleton looked at the subject from the naval aspect, and this led to a point which ought to be made.

The development of these light high-power engines was a very expensive business; for all successful aero-engines it had cost millions of pounds. Who was going to pay for this now that the turbine had conquered the aircraft field? He hoped the author was right in predicting a sizeable industrial market for these engines, but he had his doubts. Until someone did persuade the shipowner to adopt multiple high-speed engines the only important market was the railways, and most of their bread and butter was earned by units of under 1,000 h.p. For tanks, and so forth the 2,000 h.p. engine needed a 2,000 h.p. gearbox, and that was some way in the future.

This meant that if the Admiralty wanted engines of this type, they would have to pay the piper; inevitably, they would also call the tune. Other users would have to make do with the crumbs from the rich man's table; that was to say, they would have to accept naval engines derated and with minor modifications. That was what had happened in the case of civil aircraft engines.

For these high powers the gas turbine seemed likely to be a dangerous competitor, later if not now, and to meet this challenge the piston engine designer would have to pull up his socks (or perhaps roll up his sleeves. He thought the author dismissed the sleeve valve engine too lightly). The gas turbine had progressed, and was still progressing, by virtue of very thorough and comprehensive research into every aspect of its being. By comparison, the piston engine had grown up in a very empirical manner, and if it was to stand up to higher duties a really serious attack would have to be made on its basic problems.

On many of these there was still, after fifty years of Diesel development, a really appalling state of ignorance. Take, for example, these two main headaches of the designer, heat flow and bearings. As regards the total heat flow to the jackets, there was a great deal of evidence, and one could estimate fairly closely the total jacket loss of any orthodox design under almost any operating conditions. What really mattered, however, was not the *total* jacket loss, which in marine work was easily dealt with, but the *local* heat flow at hot spots. One should be able, on looking at a design, to say, "Here, at such and such a load and speed, the heat flow will be about x B.Th.U. per sq. ft. per hr. The temperature must not be more than y degrees and, therefore, allowing for the thickness and conductivity of the liner metal, I must provide a water speed of at least z ft. per sec." Few, if any, engines were, in fact, designed in this way, but that was not the designer's fault. He had not enough information to work on. Some work on local heat flows had, it was true, been done by Eichelberg and Chaloner on large marine engines. His own firm had done a little on high-speed engines, unfortunately mostly on petrol engines. A summary of the present state of knowledge—or rather ignorance—was given in a paper of his which appeared in the October issue of the TRANSACTIONS. This revealed how little was known on this very vital subject. The technique was there: it only wanted using.

Bearing research was another case in point. Since the days of Watt, bearings had been subjected to cyclical loads, but among the acres of literature on journal bearings, one found hardly a word on the effect of load variations. Here there was a very interesting conflict between theory and practice. Swift* had shown that in theory a bearing subject to an alternating load of half the rotational frequency should be incapable of forming an oil film. Simons† of the Batelle Institute, U.S.A., had tried this out on a mock-up and had found that it was very nearly true: the film almost disappeared, though not quite. By theory and model test, therefore, no four-stroke engine bearing had any right to live. Professor Swift realized that something was missing from his theory, and made some suggestions as to what that something was, but the paradox was one which obviously needed investigation. B.I.C.E.R.A. were, he knew, studying this problem, and would—he hoped—soon be able to throw some light on it.

So far these problems had been neglected as being everybody's business, and therefore nobody's. They were of importance in all engines, but vitally so in these light high-duty engines. One hoped that a concerted attack would be made on them and on other similar problems, and this paper should render a valuable service in awakening interest in the type of engine in which these problems were specially acute. As the author very rightly said, one must "leave it to George" where details were concerned, but it was only fair to give George the basic knowledge he needed.

CAPTAIN(E) W. G. PULVERTAFT, R.N., asked the author to explain why, having made out a magnificent case for the opposed-piston engine, he had then thrown it away. No case had been made out anywhere in the paper for the "H" design, apart from its square compactness. The "Jumo", on the other hand, had been described as a tried engine, one which had been in service for years and which had lightness, high efficiency, and everything that was wanted. Why throw it away?

COM'R C. W. CHAPMAN said he was speaking with a certain amount of trepidation, as whilst he was in general agreement with many of the points put forward by the author, he was afraid he did not see eye to eye with him on others, whilst some of what he was about to say might possibly savour of politics —a most unsavoury subject.

He would like first to make a few remarks about the T.12 engine. Commander Middleton said that he was not cognisant of the early history of the development of this engine and had

* Proc.Inst.C.E., Paper 5070, 1937, p. 161.

† A.S.M.E. Pre-print 49-A-41.

also pointed out in his introduction that unlike the German and American designs neither of the British designs went into production. The reason why was simple, and possibly the brief history (necessarily very abridged) which he proposed to relate might throw some light on why Britain lagged behind. He knew little of the background of the Paxman engine but a lot about the T.12. He had had the doubtful honour of being responsible for it from its inception to type test. Commander Middleton's dates were—he thought—slightly wrong, and if some of his own dates and figures were also somewhat out, he hoped he might be forgiven, for he was speaking from memory after a decade of so. At least they would be of the right general order.

Around 1938 his firm was given an Air Ministry contract to develop a single cylinder compression ignition unit with a target of around 200 b.m.e.p. When war broke out this unit had done a limited amount of running and the results were not without promise.

If he remembered rightly, it was just after the war commenced that the contract for the T.12 was placed. No preliminary design work had been done and the target was an engine of 1,000 h.p. to fit in the same space as the Merlin and, with fuel for 500 miles, to weigh no more than the Merlin. It was wanted "yesterday"—there were no Merlins to spare and nothing else was available. The contract figure was, he thought, £13,500 or thereabouts, and this had to cover the expense of three engines, including design, development, shop equipment and the actual production—truly a noble sum for such an enterprise! The first engine, after various vicissitudes and an oscillating priority falling from A1 to minus infinity, was running on the test bed and approaching a usable proposition by early 1942, rather over two years. It was essentially a cast-iron engine. No special materials were available; aluminium alloys were at a premium and they were only allowed virgin light alloy for the crankcase—the bed, cylinders and heads being cast iron. Nitrided cranks were wanted but were unobtainable.

One Monday morning early in the spring of 1942 various officials from the M.A.P. were due at the works to consider details for the boat installation, but only one of them appeared. On enquiry, it transpired that the contract had been cancelled over the weekend, no reason being given. He had visited the M.A.P. the next morning and had discovered that the engine development section responsible for fathering the engine knew nothing of any such cancellation. By a certain amount of—should he say "Nelson's blind eye" procedure?—it was agreed (quite unofficially) that he should carry on as though nothing had happened, and if he could rush the engine through a type test within a couple of months, well, "there would be a case to fight on". Imagine rushing a Ministry type test on an engine of that type in a little over two years from inception with no priority in wartime and with the executioner's axe already poised. As Commander Middleton had said, the engine did pass its test (he might add just—with a shove!), and the rest of its unhappy life story had already been told. Was it any wonder that this particular engine never got into production?

With the author, he believed that a British engine was badly wanted, but with the advent of the gas turbine his project "A" power was, he thought, too high. Without being in the inner councils he would have thought 1,500/2,000 h.p. the top figure, the engine to be used as an economical cruising engine, gas turbines being used for the comparatively short bursts of speed where compact power was of more importance than fuel economy.

Commander Middleton had referred to the General Motors "Pancake" engine and had stated that the complexity of the installation was no handicap on reliability because the individual components had been thoroughly developed and tested on shore. This was, of course, the prerequisite of any successful development project. It must be thoroughly developed, given a definite priority and consistent backing, adequate time, and adequate finance.

If, however, this projected engine was of real importance—and with the author he thought it was—he was of opinion that it should be a national project. He thought that the main field for this highly rated very light engine would be for the fighting services and that the expense of development could scarcely be justified on purely commercial grounds. However, to choose one type of engine in committee (where usually the strongest personality rather than the soundest judgment swayed the vote) and to go all out for that one alone was, he thought, wrong. Opinions were too divided, and there was not sufficient practical evidence to say whether this cycle or that cycle was the correct one, or this form or that form. The wrong engine might conceivably mean the losing of a war; at best, it might mean a heavy sacrifice in lives and material.

Commander Middleton had an excellent knowledge of his subject, and he chose the "H" form, exhaust valve controlled two-stroke. Personally he had had a certain amount of experience but he would choose a four-stroke.

His own opinion was that if the project was worth considering, at least four engine types should be developed, two two-cycle, two four-cycle, with different geometric layouts, and the one which showed the most promise should be the one chosen for final development. Liners in ports were all very well; but in his humble opinion, ports in liners should be barred. As for four exhaust valves hopping about at 2,400 r.p.m. on a six inch two-stroke cylinder—please! No. Surely the amount of power which could be developed by any engine depended upon the amount of air which could be trapped in the engine in a given time, and for a given size blower and charge cooler surely more air could be trapped in a four-stroke cylinder of a given capacity than a two-stroke cylinder. He would rather bank on 200 b.m.e.p. at 2,700 r.p.m. on a four-stroke than 110 b.m.e.p. at 2,400 r.p.m. on a two-stroke, certainly so far as maintenance was concerned.

The author stated that the two-stroke had a marked advantage in weight. If he remembered rightly, the T.12 weight quoted included the engine bearer girders and also the gearbox, as well as duplicated auxiliaries; and as previously stated, the engine was largely constructed of cast iron. Even so, it was lighter than the "Pancake", the only comparable two-stroke.

As to the engine's form, there was much to be said for the General Motors "Pancake". Of all Diesel engine rooms he had ever seen, none was more accessible and pleasing and compact than the one he had had the privilege of seeing on the special service craft fitted with these engines. As the author said, the engines gave very little trouble, and all that those he had seen had behind them for servicing was a wooden shed and equipment that the average garage would have scorned.

Servicing *in situ* was essential for this class of engine and the vertical multi-row radial was ideal from this point of view. General Motors had proved that it was mechanically workable, even as a two-stroke. It had the virtue also that by taking the drive from opposite sides of the bevel, opposite directions of rotation of the propeller shaft were available from a standard engine. He did not think any other geometric form was likely to be so compact or, indeed, so light, and certainly not so accessible. As a four-stroke rated at 200 b.m e.p. at 2,700 r.p.m., the "Pancake" would give roughly the desired 2,000 h.p. For tanks and fighting vehicles the engine could, if necessary, be installed on a horizontal axis to retain a low silhouette.

He would then suggest as an alternative an engine generally on the lines of the G.M. "Pancake" but working on the four-stroke cycle, but unlike the author, he would not leave too much responsibiilty in the hands of the detail draughtsman. He had seen too many good projects ruined by faulty detail and manufacturing expediency.

Finally, he hoped that as a result of Commander Middleton's paper, the powers that be would, if necessary, reconsider this whole question and that if another emergency should arise a suitable power unit or units would be available in time. Last time there was nothing.

MR. A. G. HOWE remarked that the author had brought a number of problems to light. He had said that it was easy to be wise after the event, and he had in some degree reviewed the mistakes made some years previously. There was nothing wrong in making a mistake, of course, but only a fool made the same mistake twice.

There were one or two points he would like to make about the Paxman unit. Commander Chapman had told them a hard-luck story about the T.12, but there was another aspect of the case, namely what had been done to catch up with these various problems. The engine that had been described was very largely influenced at the time by the existing design of a cast-iron version. Very considerable care was exercised when changing over to light alloy. The founders had to provide good metal, at both the top and bottom of a somewhat awkward casting. There was a space for the cylinder head at the top and housing for the crankshaft at the bottom.

Was the top or the bottom end more important? They were not quite sure. However, the decision was eventually made in favour of the bottom end. Unfortunately, the various ribs and so forth were tricky, and casting faults occurred in some parts. That explained the unfortunate fracture that occurred. They then tried it the other way up. Unfortunately, as this happened to be a dry liner engine, they could not get a sound water-jacket. As had been subsequently proved, however, by making provision in the design and cutting off the top, leaving the crankcase as a simple piece, it was possible to produce good castings without any difficulty. Within months of this project being given up, engines of the revised design were running—in cast iron, he must confess—but quite satisfactorily.

It would be of interest, perhaps, that in addition an engine of precisely this design in three pieces made in light alloy and without any fundamental change had been running in a power house for the last two winter seasons very satisfactorily. He mentioned this in order to indicate a cure for what was the major problem at the time—one which defeated the whole project.

There were one or two other features that came out of this. The cylinder head gasket trouble had now been overcome by development of material, chiefly of the reinforced type. The engine he had described as being in service had the same type of cylinder head gasket but it was made in material which had given no trouble at all. When one reached the stage of separate cylinder heads with, possibly, wet liners, one could introduce a spigot type of joint which was probably better in the long run.

Mention had been made of bearings and the problems that occurred with them. There was a bogey at that time, and this bogey had not been entirely frightened away, namely that it was quite wrong to run a copper-lead bearing with what was then called a "soft" shaft. It had been proved in many cases subsequently that it was nothing more than a bogey, and that with adequate filtration copper-lead bearings could very satisfactorily be operated for long periods with a relatively soft shaft—at least a 0·4 per cent carbon shaft.

At that time there was a struggle for a bearing material which would be soft enough to operate with a relatively soft shaft without producing undue wear, and materials like "Satco" was used at that stage, "Satco" being a type of hardened lead; but it really was not good enough.

The author had said the crankshaft would have been better had it been balanced, but he was under the impression that it was balanced with balance weights. It was certainly dynamically balanced, though that of course, was not the same thing.

The author had also said, with regard to the general construction of the crankcase, that the crankcase door was not a necessary feature, or at least he thought subsequent events proved it was not necessary. He himself would suggest that short of taking off the sump to get at the connecting rods and pistons, it was essential. If one had a crankshaft of reasonable dimensions, stiff enough to deal with torsionals and other things (this was before the days of viscous dampers) the big end was too big to go up through the cylinder bore. It was therefore necessary either to drop the sump and take the pistons and rods out that way, or to provide something in the nature of a crankcase door through which one could move the pistons and rods. It had been found quite possible—since that time—to make a crankcase in this way.

The author had mentioned that air starting was perhaps rather a lot to expect from so small an engine. Nowadays, very useful air starting motors had been produced, and that was perhaps the answer to this particular problem. Air was very frequently used and was sometimes much better than electrics for starting purposes. Air was quite a feasible starting medium, but with an air starting motor rather than through to the cylinder head.

As Commander Chapman had said, it was the period through which they were living that really decided whether the engine continued to be worth exploring, but it was a pity that the manufacture of the crankcase had beaten them at the time, because there were a number of very interesting features in the engine, not the least being the gearbox. It was built into the engine and was a combination—peculiar as it might seem—of the S.L.M. clutch with a Wilson reverse-reduction unit, all inside a Wellman-Bibby coupling. But there was not time enough to try it out in practice.

That brought him to the end of his comments on the Paxman unit, but he would like to make one or two remarks which he hoped would not sound too pessimistic concerning the type of engine which might be envisaged for the sort of work that was in mind. Very fancy fabricated work might be shied at, and therefore the more ordinary and orthodox the engine the better would be the production and the more satisfactory the problems connected with maintenance and other features.

To take the Paxman unit, it was within fairly useful distance on the weight factor. It was not very far out with regard to power. Its general performance was reasonable, and it was a fairly orthodox engine. One ought not to stray too far away from what was easily produced, readily maintained and at the same time gave a useful performance.

ENG'R REAR-ADMIRAL D. J. HOARE said that the way in which the author had managed to pack so much information about five very important engines into a single paper had already been appreciatively mentioned. There was one somewhat unfortunate aspect of this: that it encouraged comparison, particularly as between two fully developed German engines and two obviously under-developed British ones.

Both of the German engines described were the result of extensive research and many years of intensive development, and they embodied the knowledge and experience obtained from a large number of forerunners. The British engines—as the author and other speakers had already made clear—were both the outcome of a hurried attempt to produce an engine in very limited time and with limited means.

He fancied that in the lessons to be learned which the author had referred to in two or three different places, insufficient emphasis had been given to the laborious and expensive nature of engine development: going through component testing, unit testing, a great deal of scrapping and rebuilding, and also to the amount of scientific knowledge and research entailed.

The author might, of course, have made light of the matter in order to coax some engine-maker into the business, and he had, indeed, referred to possible commercial exploitations. The markets mentioned, however, were not such as would recompense anybody for the amount that would have to be spent in development; nor would the civil applications, particularly the mobile ones, demand the qualities specified for the engine. The engine, in fact, would price itself out of most competitive lines.

In view of the fact that the Germans in the last war were, as had been pointed out, loading 2,500 h.p. on to a shaft, he could not help thinking that the power target ought to be higher in anticipation of another event. He was inclined to agree with Commander Chapman's solution—to put the high power in the form of gas turbines and use Diesel engines for getting one about the place over long distances.

MR. A. F. EVANS (Member) said that he felt that it was a tragedy that the Junkers "Jumo" engine came to such a bad end in this country. When it was tested it gave a far better performance than any other available engine but he did not think that it was able to sustain more than about 110lb. b.m.e.p., and it was scrapped for this reason.

The tragedy was that in this country, at the time, there were two commercial engines of this make which were giving 145lb. b.m.e.p. and one of them, at least, was able to sustain 125lb.

The reasons why the Junkers "Jumo" failed were quite simple and quite clear, while the means that would have been applied to rectify the difficulty were also clear and simple. The factors that prevented this rectification from being carried out were entirely non-technical. If this engine had been satisfactory it is quite possible that one might be using Diesel engines in the air for commercial aircraft at the present time. As was well known, this type of engine had been taken up by Fairbanks Morse for locomotive and other work with great success.

In regard to the 2,000 h.p. marine propelling engine suggested by the author having a weight of 3·5lb. per h.p., this could be accomplished, but at a very high development cost. Such an engine would be of little value if it had to be discounted 30 per cent for continuous running and if the flexibility were no better than the figures suggested. A speed range having a minimum of 30 per cent was quite inadequate while the power range should be down to zero.

He was somewhat old-fashioned and he felt that for these weights and powers one should look to the gas turbine. Perhaps best of all would be two wing turbines with a Diesel engine on a centre shaft for cruising and manœuvring.

This engine could no doubt weigh 10lb. per h.p.; it would have to be reversing and able to develop its absolute full power for an indefinite period. A very flexible engine and a very quiet one would be required. He was aware that he was reverting to the destroyer *Caroline* of 1905 or thereabouts, but with Diesel propulsion instead of steam for the centre shaft.

Wrapped up in this question of noise and full power continuity was the excess amount of heat dissipated to the water-jackets. The 30 per cent or so lost must be reduced to at least one-half this amount. It was this waste heat that caused so much damage.

The motor torpedo boat had its beginnings in 1903, Thornycrofts, Yarrows, Napiers and the American boat *Gregory* were well to the fore in those days and it was in 1905 that S. F. Edage stated that a quiet engine was essential for this purpose. He gave three essentials, "Quiet running, proof against loose water in the engine room, continuity of operation for long periods at absolute full power".

At that time he had a little 20-knot boat that had run for 5,000 miles with nothing more than a normal top overhaul to the engines.

The *Gregory* was a 90 × 12 × 4 feet boat with two 300 h.p. table engines running at 400 r.p.m. This boat did 23 knots, and it was this type of engine that was used in the M.L.'s of the 1914-18 war.

Correspondence

CAPT.(E) B. H. CRONK, R.N.(ret) wrote that after reading the author's eulogy of the opposed piston type of engine and his forecast of a great future for development of this type under his description of the Junkers "Jumo 205E" engine, he was surprised at his peremptory dismissal of the type in his considerations for Project "A" solely because the British background was nebulous and that the incidence of some difficulties was fairly certain.

He remembered that the Fairbanks Morse Co. in U.S.A. was developing a two-stroke, opposed piston, four crankshaft engine known from its shape as the "Diamond" engine, contemporarily with the General Motors "Pancake", it being visualized for possible multiple installation in destroyers.

It would be interesting if the author could give any information regarding the outcome of this project and to know if the reasons for its failure to reach series production had any bearing on his preference for development of another type, in spite of the proved advantages, particularly that of the all important specific weight.

COM'R(E) PETER DU CANE, O.B.E., R.N.(ret) M.I.N.A., M.I.Mech.E., wrote that referring to Project "A", apology was tendered in advance for ignorance which might be displayed in the eyes of the more enlightened. It would, however, be interesting to know how the decision to incorporate poppet valves in lieu of the sleeves discussed in conjunction with the proposed layout would affect the practicability of compounding this engine with an exhaust gas turbine.

MR. I. WANS (Member) wrote that the paper was one which he thought would appeal to anyone interested in design as it described engines designed to fulfil certain duties without always having to consider very minutely the cost of what one was doing. In this respect he thought great credit was due to the light-weight engine produced by Messrs. Ricardo and Messrs. Davey, Paxman and Co., as generally speaking this engine was a reasonable commercial and production type of engine when compared with the Mercedes-Benz or the Junkers "Jumo". It was apparent from this paper that the German manufacturers had very much more encouragement to design the light-weight engine with a high output than they had in this country, and had taken full advantage of this encouragement.

He was not in full agreement with the author's remarks on pp. 364 and 365 under the heading of "Plans for the Future". The prospect of using the light-weight high-speed engines for emergency conditions, as for example, the flooding of the fenland in 1947, would cause apprehension. Would it not be better to use a slightly heavier but more conservatively rated engine, which must, by necessity, be more reliable? For these emergency conditions surely reliability was of great importance.

MR. O. THORNYCROFT wrote that the author gave them an interesting peep into the history of the development of two British engines, the Paxman-Ricardo Ex.239a and the Perkins T.12. The picture they saw was a dismal one indeed; but it was nevertheless clear that, had the development effort on these engines been comparable with that given to the German ones, the British engines would have made a creditable showing. It was not, he thought, stated in the paper, but it could be inferred from the figures given, that the supercharged Paxman-Ricardo engine had no charge-cooler while the other four-stroke engines, the Perkins and the Mercedes-Benz, had. This would account for the lower b.m.e.p. quoted for the Paxman.

The author gave reasons why so much less development effort was devoted to the light-weight Diesel in this country than in Germany; he believed the turning point was in 1930 with the loss of the airship R101 on her ill-fated maiden flight to India. As a result of that disaster the sister ship R100 was scrapped immediately after her brilliant maiden voyage across the Atlantic and back. Thus the immediate requirement for light-weight Diesel engines was removed while, in Germany, development was continued in order to provide for the needs of the Zeppelins. Leading on from Zeppelin development came Hitler's re-armament programme with the requirement for engines for small high-speed surface craft. Strategically such boats were of far more importance to Germany than to this country. Thus in Germany there had continued a high priority for light Diesel engines while in this country development was almost dropped.

Mention should, he thought, be made of a successful British light-weight Diesel. This was the *Meteorite*, developed by the Rover Company for the Ministry of Supply and now released for commercial use. The engine was an 8-cylinder version of the *Meteor* Diesel, a four-stroke, 12-cylinder Vee based on the design of the Rolls-Royce *Merlin* engine. The following performance figures for the *Meteorite* were comparable with those given in the author's Table 1, bearing in mind, however, that the *Meteorite* was not supercharged while the other four-stroke engines were.

Bore and stroke	5·4 × 6·0 inch
Power (max. B.S.I. rating)	320 b.h.p. at 2,400 r.p.m.
Max. b.h.p. per sq. in. of piston	1·75
Weight (including flywheel and bearers) ...	1,500lb.
Specific weight (as above)	4·7lb. per b.h.p.
Fuel consumption (cruising) ...	0·39lb. per b.h.p.-hr.

Under the heading "Plans for the Future" the author mentioned possible useful applications of the light-weight Diesel engine and suggested the outline of a design to meet these needs. Apart from service requirements—and these might or might not be met by the author's proposed designs—the list hardly seemed to warrant the vast expenditure involved in the development of an entirely new type of engine. A wider and more important field of application seemed to be required. He could not help wondering whether the time had come to consider once more the economics of the light-weight Diesel if applied to merchant ship propulsion, for example, in ships requiring up to 6,000 s.h.p. per shaft. The advantage of such engines should lie mainly in reduced engine-room space and, probably, in reduced capital cost. In order to compete with the present highly successful large Diesel engine the small light-weight engine would have to show itself equally reliable, no more costly in maintenance, equally (or nearly equally) efficient in fuel consumption and capable of running on equally cheap fuel. This did not appear impossible of achievement because the light-weight engine, with its smaller cylinder, could be de-rated and run at a lower piston speed than the large engine and still show an advantage in weight and space. The reason for this, of course, was that power was proportional to piston area while weight and space tended to vary directly with cylinder volume. In terms of dimensional theory:—

$$\text{Power} \propto L^2 \text{ while weight (and volume)} \propto L^3$$
$$\text{thus specific weight (and volume)} \propto L^3/L^2 = L.$$

This was true of geometrically similar engines with equal piston speeds and equal mean effective pressures.

Several years ago Ricardo proposed the use of a large number of small engines for ship propulsion with electrical transmission. Since those days the hydraulic clutch had been fully developed and it was now known how to produce really accurate gears. The problem of coupling several engines together mechanically had thus been virtually solved. It required no great flight of fancy to picture four engines, each of 1,500 b.h.p. and with 6-inch diameter pistons as suggested by the author, coupled to a single spur wheel to give 6,000 s.h.p. per shaft.

COM'R(E) C. P. G. WALKER, D.S.C., R.N., wrote that the author's paper was most interesting and could not fail to stimulate thought on the best way to develop the Diesel engine in the direction of obtaining higher power-weight ratio. He found it rather surprising that in Project "A" the author rejected the opposed piston engine in spite of the spectacular example of the Junkers engine's specific weight. The reasons for its rejection did not seem to him to be entirely convincing; he would have thought that the problems the author mentioned could well be overcome by proper development, and perhaps more easily than the problems associated with the valve gear of the through scavenge engine.

Table 1 could perhaps be improved by the addition of the overall dimensions of the engines, as space was more important than weight in many applications. This consideration was probably in favour of the author's choice of the "H" type engine for future development.

Whilst agreeing that there was a naval demand for an engine of the type suggested by Commander Middleton, he was doubtful of there being much demand for such an engine for army use and even more doubtful of there being a civilian demand. Unless made in very large numbers this sort of engine was bound to be expensive, although if the demand was large enough it could be very cheap on the basis of first cost per horse-power. Maintenance costs might, however, be very heavy and the user would have to provide numbers of spare engines, or pay for their provision by the manufacturer. Unless the American market for Diesel locomotive engines could be captured (a tall order!) the demand in this field could not be large. Further, it was doubtful whether electrical transmission equipment was sufficiently developed to take advantage of the high speed of the ultra light-weight engine; development of this engine for rail traction demanded parallel development of light-weight electrical equipment.

It was interesting to speculate on the cost and time necessary to develop an engine of the type suggested. It might need five years and cost anything between one and three million pounds. He would not think there any firm of Diesel engine manufacturers in Great Britain who could contemplate a development of this nature on their own account; the work would have to be on the Government's account or sponsored by the Diesel engine industry as a whole in the firm expectation of successful development and a marketable product.

MR. A. G. HOWE wrote that Commander Middleton in his subsequent remarks at the meeting said that the crankcase of the Mercedes Benz engine was a much more difficult task than that of the Paxman engine by reason of its greater length. He would suggest respectfully that the method of manufacture adopted by the Germans proved the point he was trying to make—namely that if the water jackets were removed from the casting as a whole, then the problem was relatively simple and the additional length of the German unit would not have been a very serious problem anyway.

Author's Reply

COMMANDER MIDDLETON, replying to the discussion said that two or three people at least had thrown into the arena the very vexed and complex question whether to use gas turbines or piston engines for the powers he had been talking about. This was a matter which could only be dealt with by another paper, and he hoped one which would be given before the Institute by someone much better qualified to speak on the matter than he.

Captain Pulvertaft had asked why he had made a case for an opposed-piston engine and then discarded it. He had made the case because the engine made the case for itself beyond argument and beyond dispute. He had discarded it because he had been considering development in this country, and so far as he was aware the development of the opposed-piston engine had been carried out almost exclusively in other countries. Had he been proposing the development of an engine of this type in Germany, for instance, he would have been in no doubt as to the type to choose.

He was very grateful to Commander Chapman for the extremely interesting remarks he had made and the very revealing history he had given of the early development of the T.12 engine. The somewhat wide development envisaged by Commander Chapman, which—he must confess—approached to the ideal, was even more ambitious in terms of magnitude and expense than he himself dared to put forward with the possibility of national and even international backing. But no doubt if Commander Chapman could be as persuasive elsewhere as he had been that evening, he might yet carry the day in that respect.

Mr. Howe had given some illuminating details as to the Paxman-Ricardo engine and considered—and he himself agreed with this—that one must always bear simplicity in mind in designing these engines. But again and again one was faced with the question of working to one's specific weight when one was using the simple materials and simple foundry methods which Mr. Howe advocated on grounds of economy. Mr. Howe had spoken of the difficult problem of producing the Paxman-Ricardo "239A" crankcase, but he would point here to the crankcase of the Mercedes-Benz—a problem which must eclipse the one with which Mr. Howe had had to deal.

He agreed with Mr. Howe that crankcase doors must be provided in any engine of this type if there was a requirement to change pistons or big end bearings without removing the engine from its bed. It had been, however, his experience that when repairs which involved changing such components were needed they were better carried out in an overhaul shop, and a complete spare engine installed. Consequently the requirement did not arise, and so, need not be met.

Admiral Hoare had perhaps accused him of making unfair comparisons between fully developed German engines and only partially developed British engines. That, he feared, was to some extent true. But the point he wanted to make was that when time was available it should be used to good purpose. The Germans had at least used their time between the wars to bring their developments to a high state of perfection. In this country time had in many cases been squandered, and it was one of the objects of the paper to induce sufficient interest to ensure that the same mistake was not made again.

He had been most interested to hear from Mr. Evans new figures of the Jumo's performance, figures of which he had not been aware. They would no doubt do even more to enhance the reputation of the opposed-piston two-stroke. Mr. Evans had spoken of the continuous rating being identical with full power rating, and that, of course, was commonplace commercial practice. But he was afraid the paper was written and conceived largely with the naval or military point of view in mind, where it was the accepted practice that the continuous rating should be lower than that which the engine could develop over short periods.

Replying to CAPT. CRONK the author wrote that the reasons for discarding the opposed piston engine were outlined in his reply to Captain Pulvertaft. This question had been raised by so many well-informed people that the author felt that he must be judged a rather timorous mortal. All these people were prepared to set out to develop a design for which there was little, if any, background existing in the U.K., and additionally, to carry it considerably beyond the point to which the Germans had carried it in fifteen years of patient development. It was his view that the task of developing any engine to carry the thermal loading which he had suggested would require a considerable development effort; if, in addition, new problems of engine geometry, dynamics, and breathing had to be solved, the undertaking would be indeed a formidable one. The method he proposed was the one which, in his opinion, would produce an engine to meet the specification in the shortest time and for the smallest outlay. The opposed piston engine might have greater development potentialities, but it seemed likely that the period of gestation would be long and the cost high.

The author regretted he had no information regarding the fate of the Fairbanks Morse "Diamond" engine—his recollection was that it had a specific weight of about 15lb. per h.p., and so hardly came into the "light weight" class.

In reply to COM'R DU CANE, the author wrote that he did not think that the valving arrangement of a Diesel engine would have any significant effect on the use of an exhaust gas turbine. This was surely more a question of choosing the appropriate cycle conditions, depending on the amount of compounding desired.

In answer to MR. WANS, the author thought that for emergency conditions a light engine was needed which could be easily transported and would run on an extemporized bed. While light engines had not the durability of heavier machines, he thought that their reliability was no longer seriously questioned.

Mr. Thornycroft was, of course, right in saying that the Paxman Ricardo Ex 239A had no charge-cooler.

The details he gave of the *Meteorite* engine would be of great general interest: in view of the many doubts which had been expressed of the very light-weight engine finding a commercial market, it would be interesting to see what uses this pioneer engine would be put to by industry.

It was interesting to note that Mr. Thornycroft considered that the realization of Sir Harry Ricardo's proposal for the multi-engined merchant ship was at hand. He thought, however, that engines of rather higher specific weight and lower rotational speed, more easily adaptable to burning the heavier grades of fuel, would be tried initially. He could, indeed, recall many instances of this basic idea being followed in American coastwise and river craft.

He would refer COM'R WALKER to his replies to Captain Pulvertaft and Captain Cronk regarding his dismissal of the opposed piston type. He was in general agreement with Commander Walker's estimate of the time required and financial cost of a satisfactory engine of this type, though he thought that if some degree of technical modesty prevailed —as in "Project A"—and if the development went forward unhampered by the constant changes in policy, indecision, and revision of basic requirements, which too often went with sponsorship by a Government Department, both the time and cost could be somewhat cut down.

Most of the people who had discussed the paper had expressed the opinion that there would be no commercial market for an engine of the type projected. It must, therefore, be accepted that this was the case. It could, however, be asked, whether if such an engine were available, a modest commercial market would not arise for it? The fact that an item of equipment was available, did, of itself, set a lot of people thinking how it could be used profitably. The importance of sponsoring a commercial market for machinery primarily intended for service use was incalculable, even if it had to be subsidized to some extent, because it kept the volume of production sufficiently great to justify the capital cost required for efficient production by specialized equipment, and provided a reservoir to draw on in the initial stages of an emergency before production could be increased to meet demand.

It also seemed to have been generally agreed that there was a Naval requirement for an advanced engine on the lines discussed, and the advent of such an engine would be awaited with interest, and welcomed with acclamation as an earnest that this country was alive to its commitments and was determined not to be "caught short" again.

INSTITUTE ACTIVITIES

MINUTES OF PROCEEDINGS OF THE ORDINARY GENERAL MEETING HELD AT THE INSTITUTE ON MONDAY, 16TH OCTOBER 1950

An ordinary meeting was held at the Institute on Monday, 16th October 1950, at 5.30 p.m. Mr. G. Ormiston (Chairman of Council) was in the Chair. A paper entitled "The High-Speed Light-Weight Diesel Engine" by Com'r(E) J. H. D. Middleton, R.N.(ret) (Member) was read and discussed. Seventy-five members and visitors were present and six speakers took part in the discussion.

Mr. G. R. Hutchinson (Member) proposed the vote of thanks to the author which was accorded with acclamation.

The meeting terminated at 7.25 p.m.

MINUTES OF PROCEEDINGS OF THE ORDINARY GENERAL MEETING HELD AT THE INSTITUTE ON TUESDAY, 14TH NOVEMBER 1950

An ordinary meeting was held at the Institute on Tuesday, 14th November 1950, at 5.30 p.m. Mr. J. Turnbull (Vice-Chairman of Council) was in the Chair. A paper entitled "Some Notes on the Hardening and Heat Treatment of Steel" by Mr. G. H. Jackson was read and discussed. Seventy members and visitors were present and three speakers took part in the discussion.

Mr. W. J. Ferguson (Member of Council) proposed the vote of thanks to the author which was accorded with acclamation.

The meeting terminated at 7 p.m.

CORRESPONDENCE

1949 PARSONS MEMORIAL LECTURE

Little Grange,
Portley Wood Road,
Whyteleafe, Surrey.

The Editor,
TRANSACTIONS of The Institute of Marine Engineers,
85/88, Minories,
LONDON, E.C.3.

Dear Sir,

I am writing to you with reference to the September issue of the TRANSACTIONS which contains the paper entitled "Progress in Marine Propulsion (1910-1950)" by K. C. Barnaby. There would appear to be several mis-statements in this paper and having been responsible and closely associated with the Premier Co. for many years during the construction of their numerous leading steamships, I wish to raise certain points. I would refer you to the October 1934 issue of the TRANSACTIONS and the paper entitled "Marine Propulsion—Evolution in North Atlantic Liners".

On page J2 the typical ships fitted should only include *Laurentic* (No. 1), *Olympic,* ill-starred *Titanic* and the hospital ship *Britannic.* The *Megantic* was fitted with quadruple expansion 4-crank engines *only* and the performance of this steamer in comparison with that of the *Laurentic* was convincing on its merits (see p. 251, vol. XLVI, No. 9, October 1934).

Mr. Barnaby, I feel sure, will see from this how misleading his description is and will not mind my pointing this out.

Yours faithfully,
(Sd.) W. J. WILLETT BRUCE,
Eng'r Capt., O.B.E., R.D., R.N.R.

"Abbeymead",
Hamble,
Southampton, Hants.
3rd November 1950.

The Editor,
TRANSACTIONS of The Institute of Marine Engineers,
85/88, Minories,
LONDON, E.C.3.

Dear Sir,

I am grateful to Eng. Capt. W. J. Willett Bruce for pointing out a grievous error in trributing combination machinery to the liner *Megantic.* The original draft of the lecture included an extract from the 1908 paper by Sir Charles Parsons and Mr. R. J. Walker to the Institution of Naval Architects.

Unfortunately this extract had to be omitted, owing to lack of space, and in this compression the *Megantic* was somehow transferred to the wrong list. In view of Capt. Willett Bruce's letter, the original extract may be of interest. It is as follows:—

> "The *Velox* in 1901 (a destroyer) was the first combination vessel. The *Otaki* built and engined by Messrs. Denny of Dumbarton for the New Zealand Shipping Company was the second. About the same time, the *Laurentic* and *Megantic* were laid down by Messrs. Harland and Wolff for the Canadian service (of the White Star Line). The latter vessel (*Megantic*) was fitted with the usual quadruple-expansion engines and twin screws. In service it is stated that the combination vessel consumes 12 to 14 per cent less coal than the sister vessel".

Whilst agreeing with Capt. Willett Bruce that the *Megantic* must be eliminated from the list of combination ships, I must strongly dissent from his suggested list of only four vessels. These are all ships of the White Star Line, and such a list would imply that this company was the sole user of this type of machinery. I suggest that if we substitute the *Demosthenes* (Aberdeen Line) or *Arlanza* (Royal Mail Steam Packet Co.) for the *Megantic,* we should get a suitable list of typical ships fitted with combination machinery.

Whilst on the subject of the Parsons lecture, perhaps I may be permitted to refer to come other points about which I have also had correspondence. On p. J10 it was mentioned that the slip with hydraulic couplings at full speed was about twice that of the magnetic type. This statement was quite correct, but one correspondent felt that it might lead to the unwarranted inference that the loss of efficiency with the hydraulic type would be twice that of the magnetic, whereas in practice the efficiencies are very similar.

On p. J14 reference was made to the lack of towing tank facilities in this country, as compared with the U.S.A. Such statements have frequently appeared in the yachting press, but it seems that they do not do justice to Messrs. Denny's tank at Dumbarton. Under the able leadership of Dr. Allen now at the National Physical Laboratory, and of Mr. W. P. Walker, its present superintendent, considerable interest has been taken in the testing of sailing yacht models. The successful six metre yacht *Johan* was one of those tested at the Dumbarton tank, and it is hoped that prospective owners of new yachts will follow the good example of Mr. J. Howden Hume.

In conclusion, a distinguished Naval Officer tells me a very different reason for the abortive attempts of the picket boats to stop the *Turbinia* at the 1897 Naval Review. He says that the midshipmen in charge of the picket boats had heard that the *Turbinia* had no reverse power, and they merely wanted to see what happened if she tried to stop.

Yours faithfully,
(Sd.) K. C. BARNABY.

JUNIOR SECTION

Lecture at Southend-on-Sea

A most interesting lecture on "Air Conditioning of Ships" was given by Mr. J. K. W. MacVicar (Associate) on Monday, 16th October, at the Municipal College, Southend-on-Sea.

He spoke to an audience of some two or three hundred technical evening class students of various ages. He spoke for about three-quarters of an hour after which the meeting was thrown open to discussion. Judging by the varied nature and rapidity of the questions asked the students were obviously engrossed in the subject.

The Chairman, Mr. Wilson, Principal of the College, after approximately a further three-quarters of an hour had to declare the last question, after which he was thanked for kindly taking the Chair and allowing the use of the College's very fine hall.

Mr. H. A. Humphreys represented the Council on this occasion.

Lecture at The Polytechnic, Regent Street, W.1

Mr. J. Woolman, M.Sc., delivered a lecture entitled "Commercial Testing of Materials" at The Polytechnic, Regent Street, on Friday, 20th October 1950, to an audience of some seventy students.

Mr. R. F. Thompson (Member), Head of the Mechanical and Civil Engineering Department, took the Chair, welcomed the students present and introduced the speaker as a member of the Brown-Firth Research Laboratories.

Mr. Woolman restricted his talk to the testing of steels and illustrated his remarks throughout with a number of lantern slides. After discussing tensile and Izod impact machines he passed to hardness and emphasized the special usefulness of the mobile type of sclerescope. He showed methods of detecting cracks in micro-structures and followed by several ways in which cracks in forgings could be seen including the paraffin-whitewash, the sonic and the magnetic tests.

He particularly stressed the superiority of forgings against parts machined directly from the solid by showing the smooth continuous "flow lines" in the former in contrast to the abrupt cessation and sudden change of direction of the latter.

He concluded with a note of warning by saying that although no steel was perfect many of the failures in machine parts were due primarily to faulty design. He urged that designers should avoid sharp corners and always make generous fillets—the larger the better. Of 3,000 tests that he had recently made on fractured parts, 90 per cent of the failures had been due to faulty design and only 10 per cent due to faulty material. A number of interesting questions followed which were adequately answered by the lecturer.

The Chairman said that he had listened with extreme interest to a lecture packed with information and that such a wide field had been covered that he had experienced some difficulty in digesting so much in the limited time at the lecturer's disposal.

Mr. J. A. Tickell thanked the lecturer on behalf of the audience and endorsed the remarks concerning the necessity of generous curves in design from his own experience in the field of aircraft construction.

The audience warmly responded to the vote of thanks and the meeting closed at 8.30 p.m.

Mr. F. S. Gander (Member) represented the Council.

Lecture at Middlesbrough

On Monday, 6th November, Mr. H. Armstrong (Member) gave a lecture on the "Construction of Oil Tankers" at the Constantine Technical College, Middlesbrough.

This was a very timely subject for Teeside, as a large proportion of the ships now being built in the shipyards in that district were oil tankers. Mr. Armstrong, as a technical official of one of the largest petroleum companies and oil tanker owners, has had very extensve experience in the construction of this special class of ship, and the lecture was most informative and many examples were given showing the shipbuilding practice in America as well as in the British yards. The lecture was also illustrated by photographs shown on the screen.

The Chair was taken by Mr. J. Patton, O.B.E., and the lecture room filled with an appreciative audience, including a number of senior students from the College. Mr. J. B. Smithson, M.B.E. (Local Vice-President) represented the Council.

Lecture at Queen Mary College, E.1

An excellent lecture was given by Mr. M. W. T. Rees, B.Sc., and Mr. G. J. Tuke, B.Sc., on "Electric Propulsion of Ships" at the Queen Mary College, E.1, on Tuesday, 7th November. The meeting was fairly well attended and the lecture was very well presented and illustrated by lantern slides. Mr. A. H. Ellson took the Chair at this meeting and Mr. G. O Watson (Member) represented the Council.

LOCAL SECTIONS

Sydney

A general meeting of the Sydney Local Section was held at Science House, Sydney, on Tuesday, 17th October 1950, at 8 p.m. Mr. H. A. Garnett (Local Vice-President) was in the Chair and fifty members and guests were present.

The Honorary Secretary gave a brief review of the discussions with the Technical College authorities and the correspondence with the Secretary regarding the educational qualifications for Student members. Notice was given of the Annual Dinner on 16th November 1950 at the Carlton Hotel.

A lecture entitled "Petroleum in War and Peace" was delivered by Professor T. G. Hunter, D.Sc., who holds the Chair of Chemical Engineering in the University of Sydney. The lecture was illustrated by numerous slides and covered the use of petroleum products in fog dispersal and chemical warfare and concluded with information regarding detergents and synthetic fibres.

The following members took part in the discussion, Messrs. D. N. Findlay, H. G. Ferrier, J. H. Cowell, H. W. Lees, E. L. Buls and L. B. McDonald.

A vote of thanks to the lecturer was proposed by Mr. H. P. Weymouth and seconded by Mr. F. J. Ward and carried with acclamation.

Supper was then served and further opportunity taken for members to meet.

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