NAPIER DELTIC SEA TRIALS

BY

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INTRODUCTION

The *Journal of Naval Engineering* published an article (Vol. 7, No. 3 of July, 1954) describing the production version of the Napier Deltic engine. The present article describes the sea trial phase of its development and some of the lessons learnt. The main object of the trials was to run two 'development' Deltic engines for their estimated overhaul life, under conditions as near as possible to those which the production engines would later meet in service. This involved a 'floating test bed' which took the form of an ex-German E-boat, manned and operated by the Sea Trials Section of H.M.S. *Hornet*, aided by a Resident Engineer from Messrs. Napier's Service Department. Much valuable experience was gained which led, not only to improvements in the engine, but also to a better appreciation of its capabilities and of the extent to which naval personnel could be expected to strip and rebuild it under Service conditions.

The Boat Before Conversion

The ex-German E-boat was old and had not been fully maintained since the end of the war. This led to a spate of hull troubles and, consequently,

FIG. 1—THE CONVERTED 'E' BOAT

considerable delays later in the trials. For the long periods of all-weather running contemplated, neither the navigational equipment nor the accommodation for the ship's company were really adequate. The round-bilge hull form, however, offered seakeeping qualities to meet the requirement.

The machinery installation consisted of three Mercedes-Benz Type 511, engines, driving three shafts through gear type flexible couplings, the wing engines being arranged in the forward engine room, and the centre engine, together with the auxiliary generators, air compressors, etc., in the after engine room.

Conversion

The armament was removed, as it was no longer required, and additional navigational equipment was fitted in the existing structure. To improve the accommodation, a new wardroom was built on the upper deck, thus releasing the original for use as a chief and petty officers' mess. While these alterations were undoubtedly essential, they had an unfortunate effect. The boat now trimmed by the stern, which increased the propeller power absorption so that, above intermediate speeds, the power requirement exceeded the permitted engine output.

The wing Mercedes-Benz engines were replaced by the two Deltics, which used the original gear type flexible couplings, shafting, propellers and as much of the installation as possible, though this economy was not extended to the heat exchangers, the Deltic type being used. The engine controls and operating instruments were led back to a control room situated between the forward and after engine rooms. Two views of the Deltic engine room are shown in FIGS. 3 and 4, and FIG. 2 shows the port Deltic control position. The centre Mercedes-Benz engine was retained in the after engine room for two reasons, the first of which was to provide an insurance policy against any unforeseen difficulty

FIG. 2—THE PORT ENGINE CONTROLS

with the Deltics, as, although two engines had been running successfully on the test bed for some time, it was appreciated that some operational conditions, particularly manœuvring, could not be effectively simulated on the test bed. Secondly, the boat and propellers had been designed to absorb 7,500 b.h.p. and while it seemed possible that, with all three engines running, the agreed Deltic power/revs characteristic would be adequate, it was evident that to use the Deltics alone would mean them running at b.m.e.p.s in excess of those then accepted as limiting. It was therefore intended to adjust the Deltic power output to keep the b.m.e.p.s at the accepted normal level, by using the Mercedes as a balancing engine.

The Deltic Sea Trials Engine

The Deltic sea trials engine was an earlier development version of the engine described in Vol. 7, No. 3, of the *Journal* and, at the beginning of the trials, differed from the latter in the following principal details.

Pistons

The crown and the piston body behind the ring grooves were thinner and the oil velocities in the cooling system lower than the later type.

Clutch

The astern clutch was similar in design, but the friction linings were secured by rivets only, instead of rivets and a bond between the linings and the disc. The ahead clutch, on the other hand, was of a completely different design and included a friction clutch for overspeeding the output shaft before the engagement of a dog clutch, which provided a positive ahead drive. The production engine has a two-plate friction clutch to carry the ahead drive.

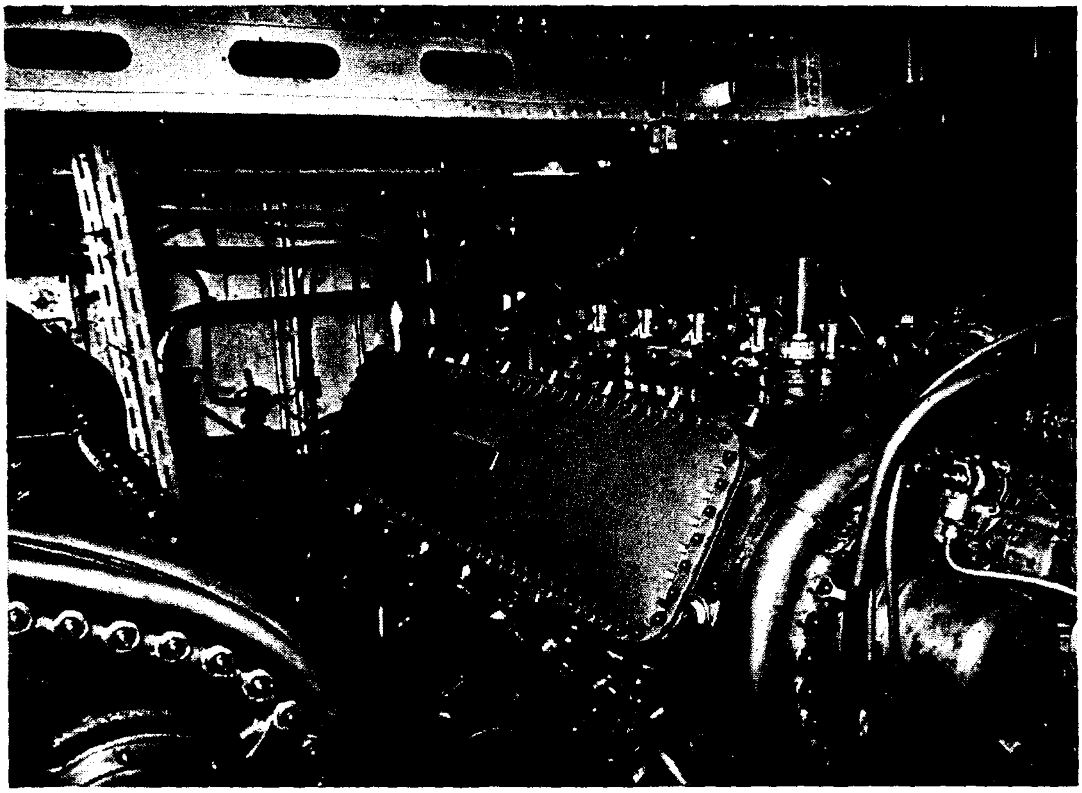

FIG. 3—THE DELTIC ENGINE ROOM LOOKING FORWARD

Injection Equipment

Inward opening needle valve type nozzles and fully compensated pump plungers were used, compared with the later engine's outward opening check valve nozzles, semi-compensated pump plungers and modified cam profile.

Governor

The sea trials engine governor was basically similar to the production governor, but the former contained no devices to limit the torque output, or to reduce the run-up during clutch engagements. An accumulator to provide the pressurized fuel for the servo was included, but the second small accumulator, to perform the same function for the governor, was not.

Exhaust Manifolds

Two separate exhaust manifolds were used on each bank, each manifold taking the exhaust from three cylinders. These were later replaced by one manifold, which took the exhaust from the whole bank.

Cylinder Liners

The outer sealing-ring carrying land at the exhaust end of the liner consisted of a screwed-on ring finally secured by soldering. The sealing ring carriers of production liners are integral with the liner and carry a different form of rubber sealing ring.

THE TRIALS

Hours : 0 to 514

The first engine was run in the boat, with the propeller shaft uncoupled, on 17th December, 1951, followed by the second on 11th January, 1952. Trials

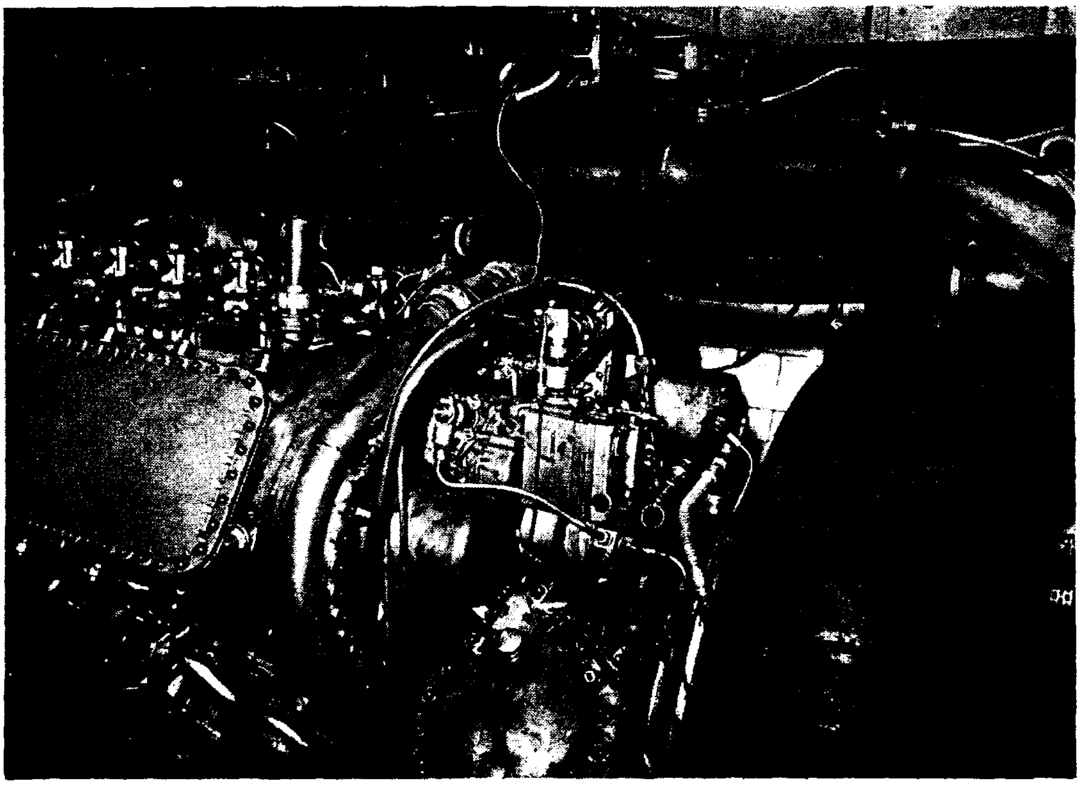

FIG. 4—THE STARBOARD DELTIC SHOWING THE THE GOVERNOR AND STARTER

at sea began on 17th January, 1952. It was immediately observed that the Deltic ahead clutch would not permit the boat to be moved ahead from rest by the Deltic engines, though the astern clutch was quite satisfactory. When the boat was stationary the period of slip in the overspeed clutch was excessive, with a risk of the dog clutch engaging heavily whilst the output shaft was still running well below synchronous speed. Provided that some ahead way was on the boat, however, a satisfactory engagement could be achieved, so the trials proceeded, aided by the Mercedes for ahead manœuvring. Early attempts to run up to full power showed that the propeller power absorption exceeded the capabilities of the engines at intermediate and higher speeds. Two attempts at adjusting the propeller absorption by cropping the blades were made without success, but a third attempt, with new propellers, provided a temporarily acceptable answer.

Following the completion of the preliminary exploratory trials, the boat settled down to endurance running on a cycle devised to simulate operational conditions and consisting of :—

5 Hours Maximum continuous running
4 Hours Idling

Acceleration to full power
$\frac{1}{4}$ Hour Full power
5 Hours Maximum continuous running

In a long day one full cycle would be run, but this was curtailed on days when fuelling was required. After some experience of the trials one day in harbour a week was introduced primarily to permit adequate maintenance of the ex-German auxiliaries and to give the crew a break. The running hours piled up steadily during the summer, though they were constantly interrupted by the necessity to make good hull and Mercedes engine defects. On one occasion the entire rudder disappeared at sea and left a six-inch hole in the bottom of the tiller flat. The Mercedes was extremely useful as a power balancing engine for the two Deltics and, while the Deltics were used for astern manœuvring, it took the main load of the ahead manœuvring. In the early running, due to the alteration in the trim of the boat occasioned by the conversion, the Mercedes had run under full b.m.e.p. conditions and probably a little above, but the introduction of propeller cropping effectively reduced the power contribution required from the centre engine and it was never again operated above its cruising power. Even so, it was a frequent source of trouble and it finally became necessary, after some 200-hours running had been completed by the Deltics, to change it for a spare which, unfortunately, proved to be just as troublesome.

In the early Autumn, after some 514 hours at sea had been run by each of the Deltic engines, an increase in breathing from the crankcase breathers of one Deltic indicated an incipient failure of the piston ring insert bond in one or more pistons. It was decided to take the opportunity to modify both engines to include a number of improvements which had been developed at Messrs. Napier's works.

Modernization and Reinstallation

Both engines were removed from the boat and returned to Messrs. Napier's works, where they were stripped only as far as was necessary to enable the engines to be brought up to a standard incorporating the latest pistons and the hydraulically operated two-plate friction clutches, in place of the friction actuated ahead dog clutches. Because of the nature of the engine, the piston change involved the removal of the crankshafts, and it was possible to examine the engine fairly fully.

The bearings and crankshaft journals were in excellent condition, there being no sensible wear in either. The bearings are lead plated, the thickness of the lead being only about 0·0007 in, but, apart from the occasional high spot, due generally to the presence of dirt behind the bearing strip, in no case was the lead plating worn away. The exhaust pistons, as had been expected, showed complete carbon blockage of the cooling grooves in the top of the gudgeon pin housing. Four exhaust pistons also showed partial failure of the bond between the ring insert and the piston body. The cylinder liners were in very good condition, no wear being visible. The piston rings showed normal wear, but were otherwise in good condition. There appeared to be no reason why the engine could not have completed 1,000 hours had a more satisfactory piston been fitted. A complete set of the latest pistons was now fitted in conjunction with the old liners and piston rings, with the exception of a few rings which showed signs of wear or damage. Two-plate ahead clutches, having linings bonded to the plates as well as secured by rivetting were fitted, together with the old astern clutches in which the linings were secured by rivetting only. Single exhaust manifolds were also fitted (one manifold per bank instead of two). No other major changes were made and the remainder of the parts were cleaned and replaced, but otherwise untouched.

The engines were reinstalled in the boat by the end of November, 1952. Examinations of the alignment before the removal of the engines had shown that in the worst case the engine was 0·145 in out of line with the propeller shaft, due to the settling of the flexible mountings and to distortion of the hull. The flexible couplings were in excellent condition despite the severity of their running conditions, so the engines were replaced with the original shims and the resulting mal-alignment, now in the worst case reduced to 0·094 in, accepted.

Hours : 515 to 1,242

Trials began in early December when the two-plate ahead clutches immediately demonstrated their superiority over the earlier dog clutches. The introduction of the single manifolds had also improved the engines low-speed performance and the boat could now be manœuvred ahead and astern on the Deltics. In fact, the ahead clutches could be engaged when the boat had 6-knots sternway, with only normal slip and without the engines stalling. Increased diameter, cropped propellers had been fitted while the engines were out and they proved to be a very satisfactory solution to the problem of providing a propeller absorption law which matched the engine power/revs characteristic. The matching was still not perfect, but with the aid of the centre engine to balance, the Deltic could be run under designed operating conditions over the engine speed range.

The coming of the cold weather, during and after the Christmas leave period, demonstrated that the engines were not good at cold starting when their jacket temperatures approached freezing point. At higher temperatures they were extremely good in this respect, and no difficulty had previously been experienced, either at Messrs. Napier or in the boat. Investigation showed that the time lag imposed by the governor's requirement for a quantity of pressurized fuel from its engine-driven pump before it could open the racks, resulted in the racks being opened too late to take full advantage of the starter impulse. The addition of a small accumulator to provide pressurized fuel at the right time reduced the time lag and corrected the phasing of the governor response and starter effort. Tests, in a cold chamber, of an engine fitted with a modified governor, showed that the engine would start with jacket temperatures some degrees below freezing point. No further trouble was experienced with cold starting after modified governors had been fitted to the sea trials engines.

An interesting side effect of this modification was a reduction in the gas pressures experienced in the starter because the engine started to accelerate under its own power much earlier. Later experience showed that the operating conditions in the starter were so much improved that the interval between successive decarbonizations could be doubled.

A governor modification to lower the idling speed was also introduced at this time. The engine idling speed was determined by the governor run-up, because it was necessary to avoid running near the critical speed of a resonant torsional order which was present just below the running range. By modifying the governor so that at a speed just above the critical speed the run-up was reduced to negligible proportions, it was possible to reduce the idling speed substantially without the engine falling into resonance when manœuvring. The minimum speed of the boat and the wear and tear on the clutches were consequently reduced, and the manœuvring qualities of the engine improved.

After completing some 635-hours running, increasing sparge oil pressures indicated that the sparge oil jets were blocked, and it was decided to remove the blower in the boat and to clear the sparges in the blower gearbox. The blockage appeared to be due to the faulty reassembly of a main oil filter element after inspection and not to anything attributable to the running of the engine, but as cleaning sparge jets involved a fair amount of stripping, it was decided to modify the design to include a small strainer in the oil feed to the sparges.

At this point the Mercedes engine troubles reached major proportions. The failure of three cylinder holding down bolts was followed, two days later, by a cracked cylinder. No sooner had these defects been rectified than the appearance of heavy breathing from the crankcase and metal in the scavenge filter, indicated some failure in the engine. In the interests of time no strip was carried out, but a spare engine was shipped.

From about fifty hours after the Deltic engines were modernized the port engine had shown a lag in the astern clutch engagement after protracted periods of running ahead. The opportunity to remove the gearbox and return it to Messrs. Napier for examination was seized. The gearbox was removed without great difficulty and the subsequent clutch examination showed that the astern clutch plate had distorted and appeared to be binding, that the clutch had been centrifuging the sludge out of the lubricating oil and depositing it in the pressure plate driving splines, and that there was a possibility of oil leaking from the ahead clutch to the astern and keeping the astern plate in contact when the clutch was engaged ahead. Modifications were introduced to prevent a recurrence, and the starboard gearbox was also removed and modified in the same way.

By the end of February, 1953, both gearboxes had been reinstalled and the spare Mercedes engine fitted. Running continued uneventfully, apart from slipping twice to deal with a defective rudder bush and a visit to Hammersmith, until the end of April, when the engine was released and demonstrated to the Press at H.M.S. *Hornet*. The photograph in FIG. 1 was taken on this occasion, the crowd on the upper deck being interested observers, rather than the trials team.

More Mercedes maintenance followed and five cylinders were changed because they had developed water leaks. A period of uneventful running then led to the completion of the 1,000 hours in June.

It was decided at this point that running should continue because, although the majority of the engine parts had run for a 1,000 hours and were due for overhaul, the pistons and the ahead clutches had only run approximately 500 hours. There was also a Deltic training requirement which would continue for some months and as the E-boat was the only suitable boat available for training, it was necessary to conserve engine hours to some extent. At the same time, to add to the information which had already been gained from the trials, a scheme of running, which involved the gradual relaxation of the engine running limitations, was agreed. In practice, this meant a basic change in the operation of the boat. Whereas, before, the boat had been operated on a war-time basis, running as much and as often as possible consistent with crew and maintenance limitations, it now operated under peace-time conditions, exercising in the same manner as any other Coastal Forces craft.

At the end of August, the Mercedes engine was finally removed from the boat to become a spare engine for a different trials project and the boat was subsequently operated with Deltics only. The propellers were cropped again to enable the unaided Deltics to develop full revolutions without overloading, and the boat settled down to run through the winter. At the beginning of March, when the engines had completed 1,242-hours sea time and 1,335-hours total running time, the appearance of water in the sump of the port engine led to the discovery that coolant was leaking into the sump through two cracks in the solder securing the exhaust end ring carrier to the liner. Although the rectification of this leak meant removing the engine from the boat and breaking down the triangle, the leak itself was not of great development significance as a different type of liner, in which the exhaust end ring is integral with the liner, is used in all later and production engines. The engine was removed from the boat and stripped, rebuilt and reinstalled at H.M.S. *Hornet* by naval personnel under supervision from Messrs. Napier.

A running-in schedule similar to that used on the test bed, but modified to suit the boat loadings was employed, on the completion of which, operational running continued until, at 1,305 hours sea time, the astern clutch of the starboard engine ceased to operate. The engine was removed from the boat to enable the clutch to be stripped for examination, but a quantity of water, detected

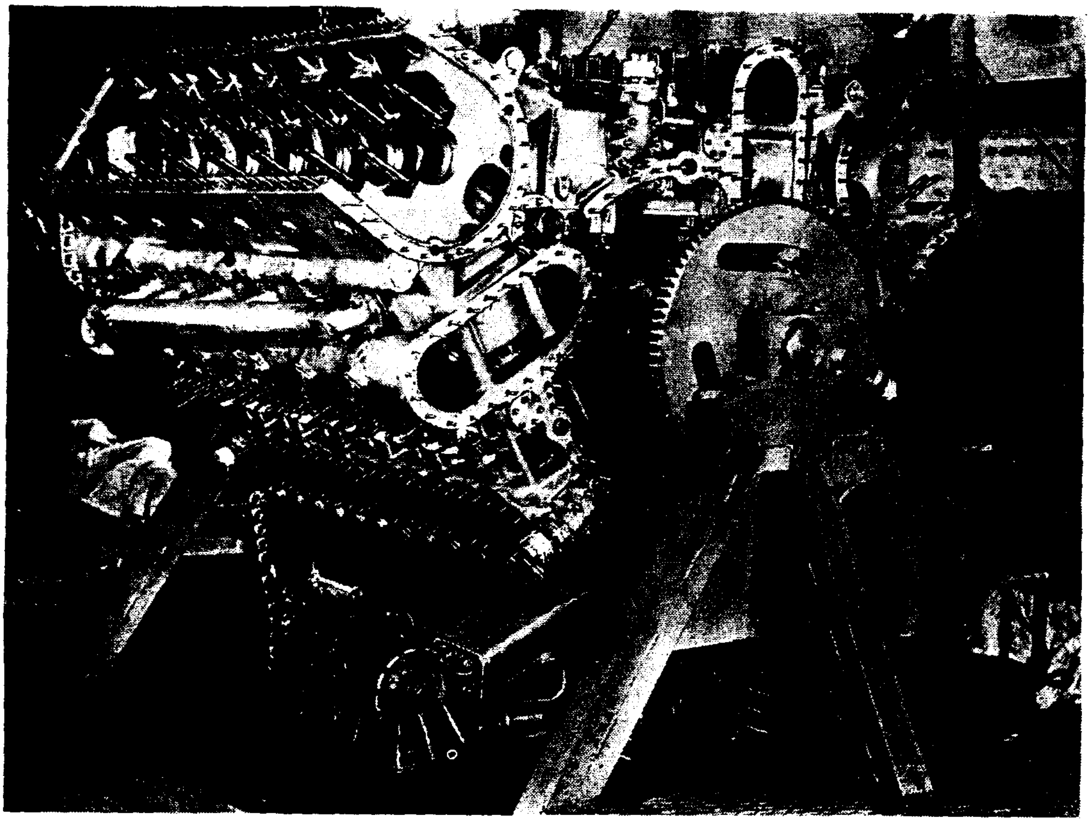

FIG. 5—PORT ENGINE TRIANGLE ON ASSEMBLY STAND

in the sump, led to the discovery that three liners were leaking through cracks in the soldering which secured the exhaust end ring carrier. A repetition of the stripping of the port engine was therefore undertaken in addition to the gearbox strip.

STRIPPING AND REBUILDING

Port Engine Strip

Following the appearance of the water leak in the port engine, a combined team from H.M.S. *Hornet* and Napiers removed the engine from the boat and stripped it as far as was necessary to return the cylinder blocks to the firm for the withdrawal of the liners and re-sweating the ring carriers. The work entailed was the removal of the engine from the boat, the removal of the reverse/reduction gearbox, phasing gearbox and blower, the removal of crankshafts, connecting rods, pistons, crankcase-mounted auxiliaries and camboxes, and breaking down the triangle to allow the separation of the blocks.

The engine was removed from the boat by the ship's staff, with the aid of the dockyard for the actual lift of the engine only, and took 49 man-hours. The special tools and stands, needed for the strip, were supplied by Messrs. Napier and the Admiralty Engineering Laboratory, and the labour force consisted of four service engineers from Napiers, only one of whom had previously stripped and rebuilt a Deltic, one C.E.R.A. and one E.R.A., both of whom had running experience of the engine in the E-boat, but whose stripping experience was limited to that acquired in minor maintenance, and two M(E)s for general duties. The strip was completed in 204 man-hours. This time included delays caused by the preparation of assemblies for photographing and by the lack of sufficient special tools, which prevented the full employment of man-power. The engine is shown in FIG. 5 on the assembly stand during the strip.

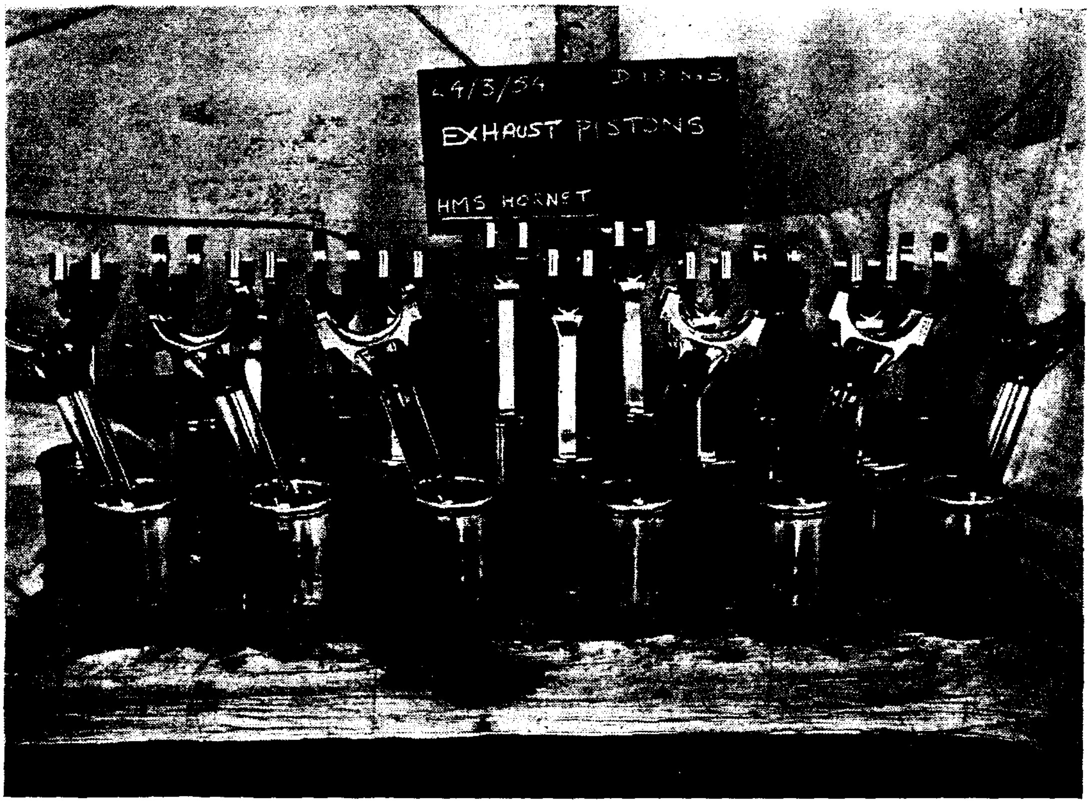

FIG. 6—PORT ENGINE EXHAUST PISTONS

Inspection

The pistons were generally in good condition though three showed signs of slight blow-by, one inlet top gas ring was broken, one piston had cracked and lost a piece from the crown land and two had suffered partial failures of the ring insert bond. No carbon had built up in the crown cooling grooves of the gudgeon pin housing and, in this respect, this piston showed a great improvement over the earlier type. Subsequent metallurgical examination of the bond failures and cracks, attributed them to a sharp corner on the ring groove insert. The remainder of the engine was in very good condition, the bearings, crankshaft and liners showing no sensible wear. The pistons and the large-end bearings as removed from the engine are shown in FIGS. 6, 7 and 8.

The Port Engine Rebuild

The engine was rebuilt with three new pistons in place of those damaged, one new inlet piston ring in place of the broken ring, and new compression rings in the third ring groove of the exhaust pistons, the old third ring being transferred to the top groove and the old top rings discarded. These items, together with the tab washers, joint washers and split pins disturbed on stripping, were the only spares fitted. The rebuild was carried out with the same labour force as the strip and was completed in 339 man-hours. It included phasing crankshafts, timing injection pumps and priming the injection system. The engine was reinstalled by the ship's staff with the aid of a mobile crane, in the tidal waters at H.M.S. *Hornet*. The installation amounted to 56 man-hours. The alignment of the engine on reinstallation was set up to that obtaining before removal, which meant that the engine output shaft was approximately 0·140 in out of line with the propeller shafting. No attempt was made to improve on this alignment, as the flexible coupling had run under this condition

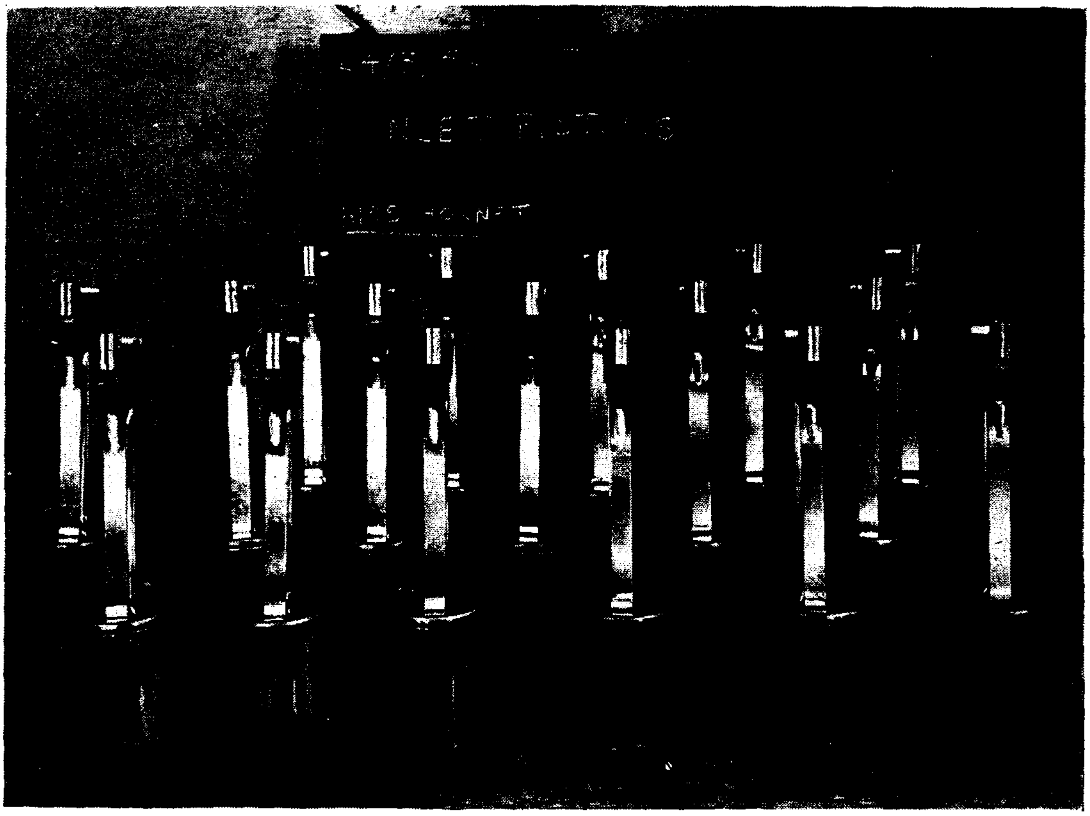

FIG. 7—PORT ENGINE INLET PISTONS

for some considerable time and the capacity of the coupling to run out of line was of great interest.

The Starboard Engine Strip

The astern clutch failure which occurred in the starboard engine, after 1,305-hours running, led to the decision that H.M.S. *Hornet* should remove the engine from the boat, remove the reverse/reduction gearbox, remove the clutch from the gearbox and return it to Napiers for examination. When the engine was removed from the boat, however, the presence of water in the sump led to the discovery that three liners were leaking in a similar manner to those already repaired in the port engine. The port engine strip, in addition to the gearbox stripping, was therefore undertaken. The internal condition of the engine was most satisfactory save that three pistons had cracked, two having lost pieces from the crown land. This failure was identical with that experienced in the port engine. The failure of the astern clutch was due to the break-up of the lining. Apart from the fact that the clutch had run 300 hours over its overhaul life and shared in over 11,000 engine movements, the lining securing arrangements consisted only of rivets, which was known by this time, to be a method much inferior to the combination of rivetting and bonding used in later clutches. The ahead clutch, which had the later form of securing arrangements, had run for 800 hours and shared in over 7,000 engine movements, but the condition of the plates was excellent, and the wear was so little that the lining thicknesses were still within the drawing tolerances.

The engine was rebuilt after the liners and the clutch had been repaired, with three new pistons and a new astern clutch plate. The astern clutch pressure and reaction plates were also trued up before replacement.

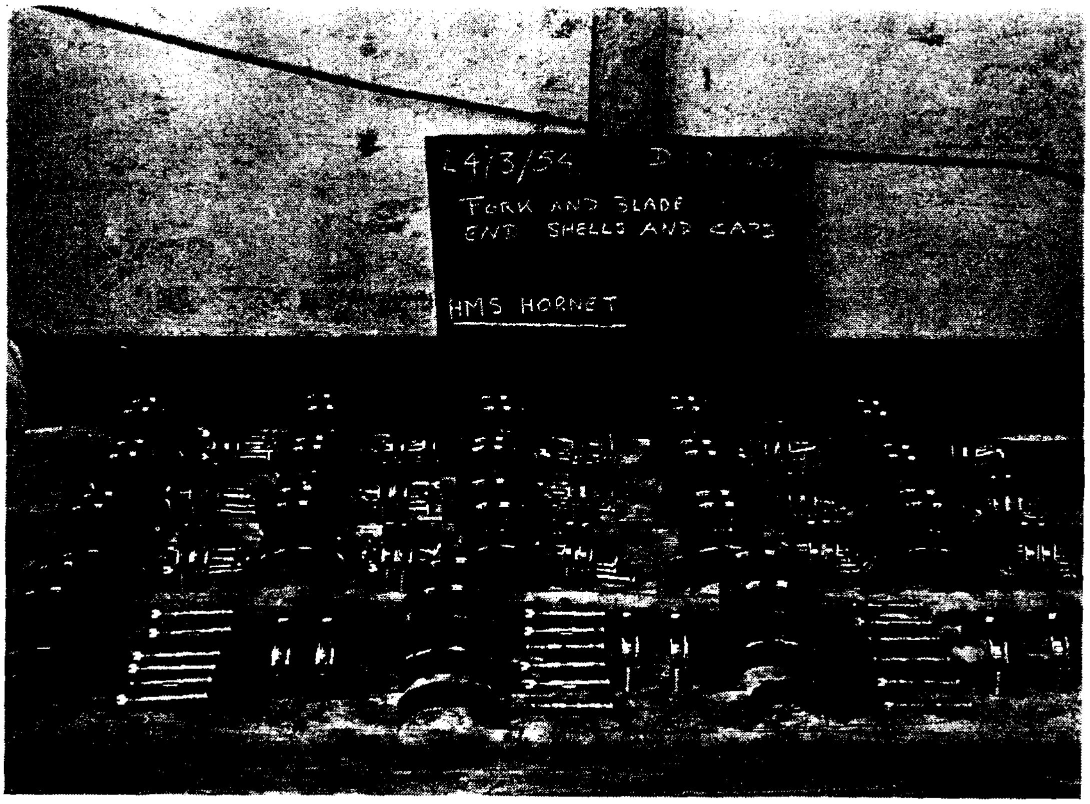

FIG. 8—PORT ENGINE LARGE END SHELLS AND CAPS

The man-hours expended on the whole operation, not of course including the repair effort at Napier's works, were :—

Removal from boat	—	48 Man-hours
Strip	—	142 Man-hours
Rebuild	—	244 Man-hours
Reinstallation	—	60 Man-hours

CONCLUSIONS

Operation

The operation of the engines presented no problem, particularly after the engine modernization which introduced the production type two-plate ahead clutch. It was found possible to train naval personnel in the handling of the engines in a short time and all operators were happy with the engine control arrangements. As the sea trials were really part of the development programme, more instrumentation was fitted than would be the case in an operational boat, and the engines were run to a set of limitations which included fuel pump rack settings as well as exhaust temperatures. In the case of the production engine, a torque limiting device has been added to the governor which limits the fuel pump rack settings, thus simplifying the operation of the engine still further, as well as providing positive protection for the engine.

In common with any small, high speed, high powered engine the noise level is fairly high. However, the control arrangements provided for full control of the engines from a separate compartment, in both governor and hand control. The engines could be started from the control room and all instruments were led back to that position. Nevertheless, a watchkeeper was maintained in the engine room during the trials, and the noise level does not appear to have been high enough to preclude useful watchkeeping. As the engine is a high speed, 18-cylinder, two-stroke, the firing frequency is much higher than that usually associated with Diesel engines, giving the noise a character which is not as unpleasant as the measured noise level would suggest. Even so, the noise can be harrowing after a long period of exposure to it and a control position, in a compartment separate from the engines, is desirable.

Maintenance

If those sub-assemblies and components which were troublesome in the early part of the trial and whose troubles were cured by modification can be disregarded, there is no doubt that the engine proved itself to be very reliable, which bodes well for the future of the production engine, as it includes all the curative refinements developed during the sea trials. The engines were very clean in service and the aluminium alloys used in their construction appeared to be virtually unaffected by sea water. The E-boat was a very severe test, as far as the effect of sea water on the engines was concerned, for, in any kind of rough weather, spray entered the engine room through the air intakes and fell on the engines. At times, deposits of salt on top of the engine of up to $\frac{1}{8}$ in thickness were recorded.

Routine maintenance was virtually confined to greasing controls, inspecting, cleaning or changing filters and strainers at reasonably wide intervals, and decarbonizing the Coffman starter. This was a very satisfactory finding as the shape of the engines and the confined spaces in which they are likely to be fitted, will permit little examination of engine parts for which examination facilities have not been provided in the design (i.e. parts other than filters, strainers, fuel pumps, etc.). It also proved necessary to clean the air intake silencers about half way through the trials and to change the engine lubricating oil every 500 hours. The nozzles were removed for examination and cleaning at 500 hours, but they ran for 800 hours without cleaning after replacement. The production engine nozzles are of a different type, and it does seem possible, from test bed experience with them that, when more experience has been gained, their cleaning life may be extended to the overhaul life of the engine. Routine maintenance, then, presented no problem in the sea trial engines and should present none in the production engines.

Sub-Assembly Exchange

The design of the engine provides for the replacement of defective sub-assemblies such as, blower, reverse/reduction gearbox, phasing gearcase, auxiliary pumps, governor, starter, individual fuel pumps, etc., by spares. During the trials and the stripping, almost all sub-assemblies were removed from, and replaced on, the engines by the ship's staff. This experience has shown that, provided suitable handling equipment, stands, slings, etc., and the necessary special tools are available, sub-assembly exchange at base is practicable.

It is of interest to compare the effort involved in the strip of the port engine with that of the starboard.

	Port Man-hours	*Port Percentage*	*Starboard Man-hours*	*Starboard Percentage*
Removal from Boat ..	49	100	48	98
Strip	204	100	142	70
Rebuild	339	100	244	72
Reinstallation ..	56	100	60	107

The starboard engine strip involved the same work as in the case of the port engine, with the additional work required to remove the clutch assembly from the gearbox. In general, conditions were similar, the same handling equipment, stands, slings and labour were used, but additional special tools were available for the strip of the starboard engine. There is no doubt that the adequacy of the equipment supply was responsible for part of the 30 per cent reduction in effort and that a large part of the problem of sub-assembly exchange is solved, if suitable equipment and tools are available. It is felt, however, that the experience gained by the personnel when stripping the port engine played a large part in the time-saving. That the overall reduction in effort was so marked, suggests that there is no real difficulty in the operation. The provision of sufficient suitable equipment, and a short training course for maintenance personnel, would reap a substantial saving in the maintenance effort.

The author wishes to acknowledge the assistance he has received from H.M.S. ' Hornet '. Messrs. D. Napier and Son Ltd. and Lieutenant-Commander S. G. Pearce. R.N., in the preparation of this article.