Marine Proteus Engines for the Brave Class Patrol Boats*

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INTRODUCTION

This paper deals with with the adaptation and development of an aircraft type of gas turbine which was undertaken on behalf of the Admiralty for fitting to the Brave Class patrol boats. Since the high powered aircraft engine became available shortly after the end of the 1914-18 War it has been the accepted practice to use adaptations of aircraft engines for this type of vessel or, alternatively, engines developed by aircraft engine companies and following very largely the principles and philosophies which have arisen in the aircraft industry.

The use of aircraft techniques has not ended with the machinery but has been applied where suitable to the vessels as a whole.

Although the author is very conscious of the different considerations which apply to marine engineering, he has emphasized to some extent the application of aero-engine philosophy in approaching the problems which have arisen. It would be difficult to define exactly what is the difference between the aircraft and marine points of view and perhaps this will appear more clearly in the body of the paper than in any attempted definitions that can be given at this stage.

Traditionally, marine engineers are supposed to be highly conservative and cautious in accepting new ideas or developments. This caution is entirely understandable, but it seems to the author that, having regard to the different circumstances which exist in the two industries, the marine engineer has been in the past at least as ready to take risks and to try out new ideas as is the aircraft engineer. In general, when a new development or a new design of engine has been offered, the marine engineer has had either to refuse it or accept it with the minimum of shore testing and development background and with the maximum of uncertainty, and great courage and foresight have been displayed by marine superintendents from time to time when putting virtually experimental engines into service.

The aircraft engineer is at least as suspicious of new ideas and innovations, but by contrast to the marine engineer he is in a position to demand proof and very extensive bench and flight testing and development before he will accept them for service use. The necessity for such work arises partly from the requirements of safety and partly from economic considerations. When the time comes to order, an airline operator has not at risk a single prototype but a whole fleet of new aircraft. Before the civil aircraft engine is put into airline service fifty or more prototype engines may be built for intensive bench and flight testing extending perhaps over 40,000 hr. None but the most insignificant modification is made at any time without at least 100 hours of bench testing and there requirements of proof of the suitability of even the smallest change extends to such things as the provision of material obtained from a different supplier to an identical specification if the component is one of major importance.

THE START OF THE PROJECT

The Proteus gas turbine engines were originally designed to meet the Air Ministry's specification issued in 1945. The aircraft for which this engine specification was issued was not proceeded with but a development of the original engine has been fitted to the Bristol Britannia.

At an early stage of the development of this engine it was realized that it might have an application for marine purposes and when serious enquiries were made about this by the Admiralty and Vospers Ltd. early in 1954, the author's company were ready with preliminary proposals and a fairly clear idea as to the way in which the project should be handled.

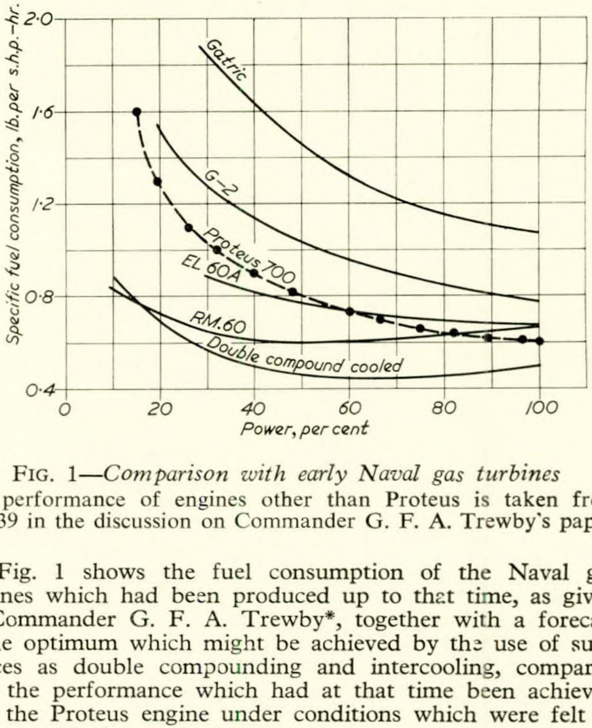

FIG. 1—*Comparison with early Naval gas turbines*

The performance of engines other than Proteus is taken from Fig. 39 in the discussion on Commander G. F. A. Trewby's paper.

Fig. 1 shows the fuel consumption of the Naval gas turbines which had been produced up to that time, as given by Commander G. F. A. Trewby*, together with a forecast of the optimum which might be achieved by the use of such devices as double compounding and intercooling, compared with the performance which had at that time been achieved with the Proteus engine under conditions which were felt to be acceptable for marine use.

It will be seen that the Proteus engine, as would be expected, shows a very substantial reduction in specific fuel consumption compared with the early naval gas turbines. Perhaps of greater significance is the fact that the consumption compares not too unfavourably with designs of considerable complication in which great sacrifices in regard to cost and weight have been made in the effort to obtain the lowest possible fuel consumption.

Some comparisons between these pioneer naval gas turbines described by Commander Trewby in 1954 may be of

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* Paper presented at a meeting of the Institution of Naval Architects and the Institute of Marine Engineers Southern Joint Branch, at Southampton, on 17th March 1959.

†Bristol Aero-Engines Ltd.

* Trewby, G. F. A. 1954. "British Naval Gas Turbines." Trans.I.Mar.E., Vol. 66, p.125.

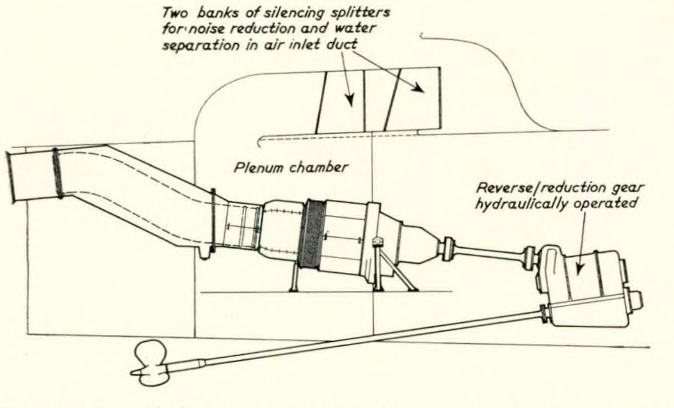


FIG. 2—*Installation arrangement of a marine Proteus engine*

interest. Compared with the Gatric, the Proteus has about half the specific consumption and is a third of the weight per s.h.p. The estimated life, based on creep data, of the hot parts is 200 times greater. The running experience at the time of going to sea is 10,000 times that of the G.2 if airline service is taken into account.

Fig. 2 shows the general layout which was proposed at a very early stage and has remained substantially unchanged since. An example of aircraft practice was the construction by Vospers Ltd. of a full scale mock-up of the greater part of the vessel, including the engine room. This proved invaluable and the idea has since been followed on other warships.

Stern exhaust was considered from the start and so was the arrangement of dividing the engine room into two compartments. Originally it was proposed to use low powered Diesel engines driving mechanically, hydraulically or electrically on to the shafts for manœuvring but it was finally decided to use a straightforward hydraulically controlled mechanical reverse gear of the Allen-Stoeckicht type.

Studies of the overall gearing problem showed that the optimum gear ratio on the engine should give a smaller reduction than that used on the aircraft engine and it was therefore decided to use a special primary reduction gear, and the design and manufacture of this was entrusted to W. H. Allen, Sons and Co. Ltd.

This change to the reduction gear constituted the only major design change as compared with the aircraft engine. The other changes involved the use of aluminium alloys in place of magnesium, a different mounting arrangement, modified engine controls and the provision of barring motors to rotate both the power turbines and gas generator in the event of one engine being stopped at sea and the others running, to avoid any possibility of brinelling of the ball and roller bearings. A gas flow diagram of the engine with the marine reduction gear fitted is shown in Fig. 3.

BENCH TESTING

The background of bench testing on the aircraft engine at high power was such that it was felt that very little other work in this direction was necessary. For example, 1,000-hr. bench test, of which 850 hours were run at turbine entry temperatures equal to or greater than those proposed for the half-hour rating to be used on the marine engine, had already been successfully carried out.

A study of engine operating conditions in Coastal Forces and of the engine running conditions in which the Bristol Aeroplane Company had experience, both in flight and on the bench, showed, however, that it would be necessary to operate for long periods at intermediate and low powers of which there was relatively little experience. It was therefore decided to concentrate on engine bench testing under conditions typical of Coastal Forces' requirements but with special emphasis on

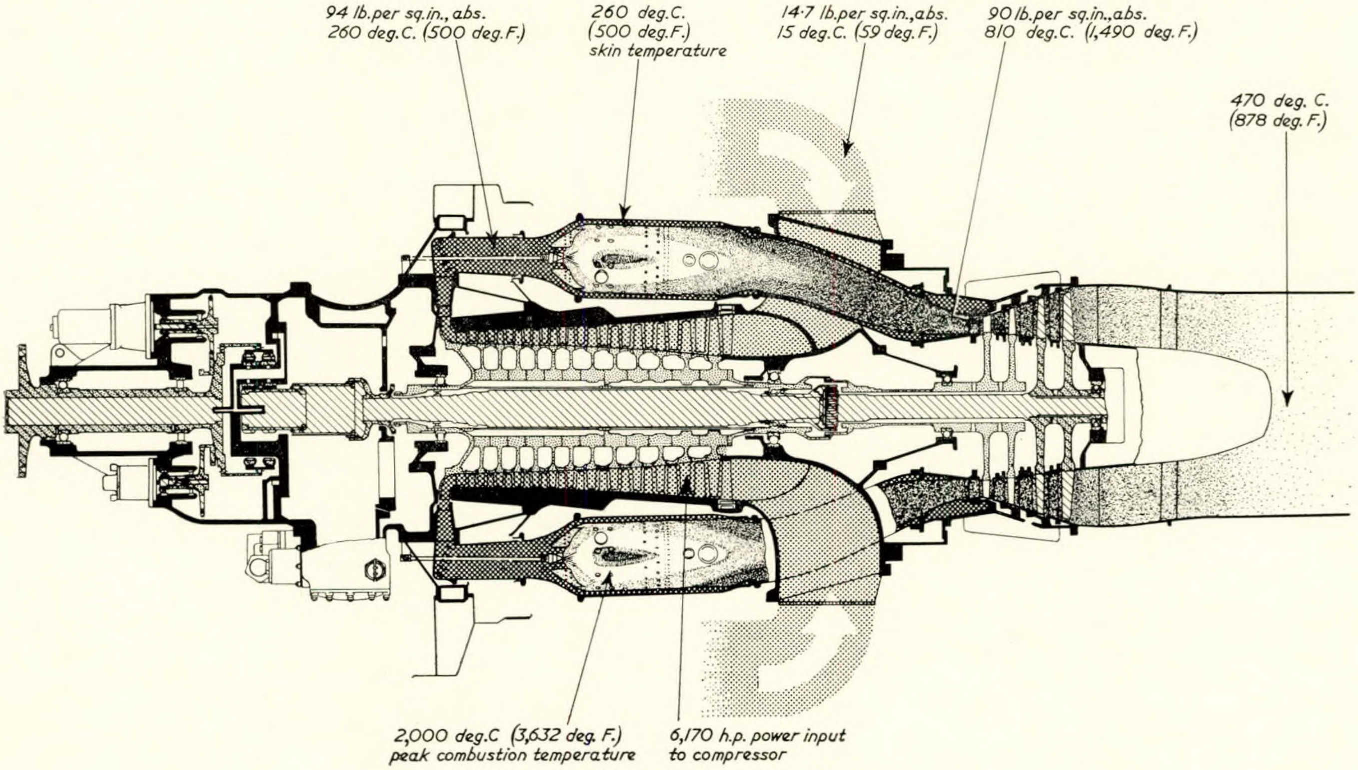


FIG. 3—*Gas flow diagram of a marine Proteus engine*

Mass air flow, 41·6 lb./sec.; 66·8 ton/hr. approximately.
Maximum power at international standard atmospheric conditions, 3,500 s.h.p.
Compression ratio, 6·4:1.

the low powered conditions. Straightforward testing under these conditions was uneventful and, having established that the engine would work well on Diesel fuel and could be run continuously at idling power, the next project was to assess the effect of sea water entering the engine air intake. Some experience in this connexion had already been gained from engines fitted to the Saunders-Roe flying boat. These engines had short periods during take-off when they habitually inhaled fantastic quantities of sea water. The ability of the engine to deal with fresh water was already in no doubt and Fig. 4 shows a bench test being carried out on a coupled Proteus engine with a fire hose directed at the intake of one engine.

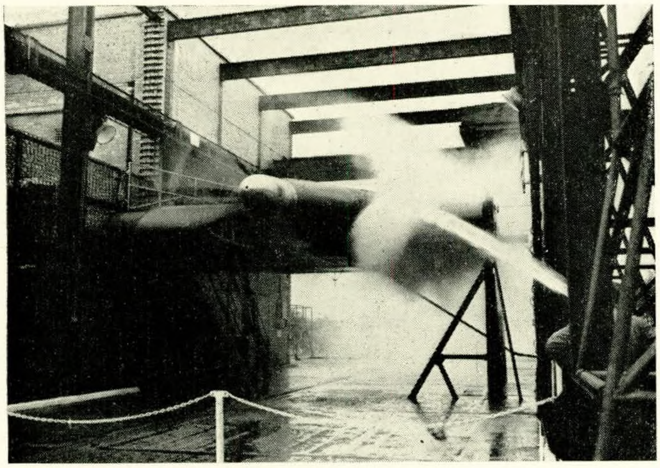


FIG. 4—*Fire hose test on a coupled Proteus engine*

Measurements of salt concentration at the compressor air intake of the gas turbine on MGB 2009 had been carried out by the Admiralty and had shown a maximum concentration in rough weather conditions of 0·5 parts per million salt to air, falling to about 0·01 parts per million in normal conditions. For the tests of the Proteus a salt concentration of 1·07 parts per million was used. The compressor was washed with one gallon of kerosene followed by 5 gal. of fresh water every 5 hr. Experience showed that during a 5-hr. period the loss in power was about 720 s.h.p. and about 620 of this could be recovered by washing with 2 gal. of water and that the full power was recovered by washing with 5 gal. During the first 125 hr. the power lost owing to salt deposits was restored by opening the throttle and the engine was run strictly to the scheduled powers. However, after this period the turbine entry temperature had risen so much as the result of fouling and corrosion of the turbine that for the last 100 hr. it became necessary to operate to a turbine entry temperature limitation of 1,125 deg. K for maximum power and 1,095 deg. K for continuous running. Previously the maximum temperature had risen to 1,150 deg. K.

TABLE I.—ENGINE PERFORMANCE BEFORE AND AFTER SALT WATER TEST

S.H.P.	Compressor r.p.m.	Turbine entry temperature, deg. K.	deg. F.	Specific fuel consumption, 1lb./s.h.p./hr.
	Initial engine performance			
3,500	11,515	1,086	1,496	0·615
2,800	11,025	1,016	1,370	0·668
	Performance after 225-hr. salt spray test			
3,500	11,400	1,135	1,583	0·64
2,800	10,975	1,071	1,469	0·70

The performance before and after this test is shown in Table I.

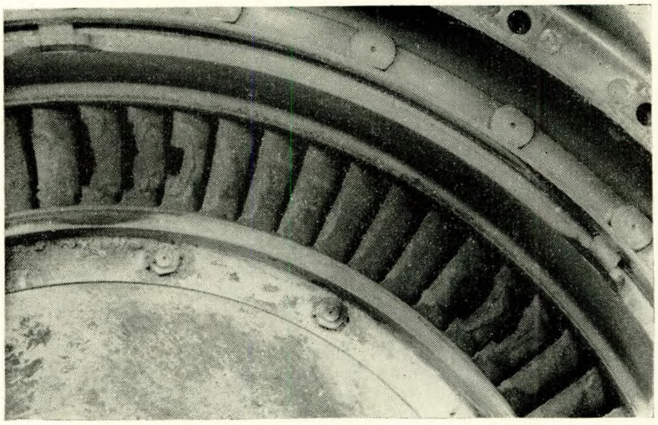


FIG. 5—*First-stage stators after engine test with sea water injection*

In view of the fact that the engine had swallowed as much salt as one would expect it to get in 1,000 hr. of normal operation, this result is not regarded as unsatisfactory. Fig. 5 shows the first stage turbine stators, which were very badly attacked by a combination of sodium chloride and sodium sulphate. It will be noted that not all the blades are badly attacked and this shows the sensitiveness to the effect of the small change in turbine entry temperature round the engine.

In spite of the rather horrid appearance of these blades, it was felt that they would probably prove satisfactory under service conditions at the designed operating temperatures. However, it seemed likely that even with the best air intake design, salt corrosion might well impose a limitation on the maximum turbine entry temperature which could be used and therefore on the ultimate development of the engine to substantially higher powers. Laboratory work was therefore instigated on a number of ceramic coatings and Fig. 6 shows the results of this work. It will be seen that complete protection is provided. Engine tests have been carried out with turbine stators treated with this material. In order to promote corrosion, 2 per cent sea water was metered into the fuel and no corrosion occurred on the treated stators. Prolonged testing under more normal conditions has shown that the coating is resistant to abrasion and thermal shock and this treatment has therefore been standardized for all first-stage turbine stators on marine engines.

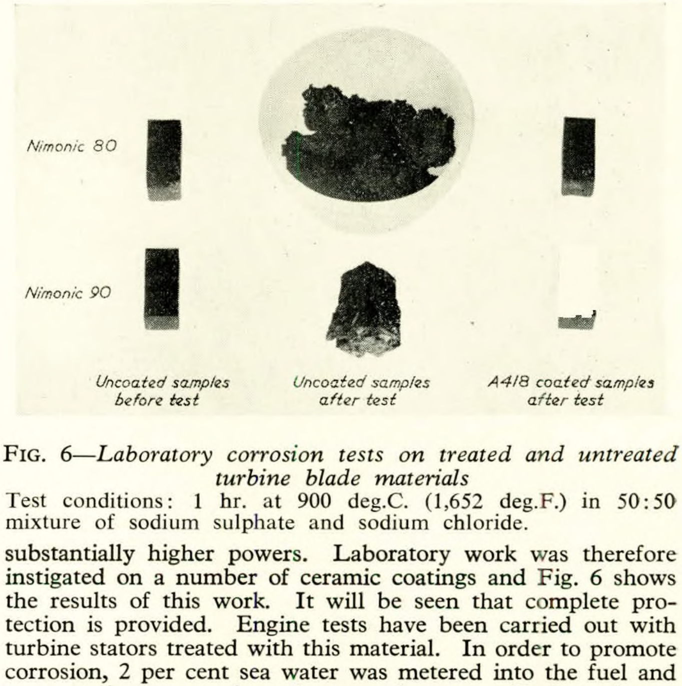


FIG. 6—*Laboratory corrosion tests on treated and untreated turbine blade materials*

Test conditions: 1 hr. at 900 deg.C. (1,652 deg.F.) in 50:50 mixture of sodium sulphate and sodium chloride.

Sea water has a very serious effect on the fatigue resistance of the best stainless steels. The exact effect depends upon the method of test and the results shown in Table II are rather extreme. The material used for the blades in the engine which was used for the salt water spray test referred to was Rex 458. These blades have now completed 575 hr.

since the start of the salt water trial, without trouble. Nevertheless it is reassuring that a steel with better corrosion fatigue properties, FV 520, is available and blades in this material have been satisfactorily tested and have been fitted for service trial in a marine Proteus engine. At a conservative estimate this steel gives a 30 per cent improvement in fatigue strength under corrosive conditions compared with the blades which have so far proved satisfactory.

TABLE II.—FATIGUE TESTS: COMPRESSOR BLADE MATERIALS

Material	Endurance in air at 10^8 cycles, tons per sq. in.	Endurance under severe sea water corrosion conditions at $5\text{x}10^7$ cycles, tons per sq. in.
DTD 282 steel	±24	±10
Rex 458 steel	±35	± 9
F.V.520 steel	±38·5	±13
DTD 197 aluminium bronze	±19·2	±10·2

SAFETY DEVICES

The engine is fitted with a low oil pressure trip and with governors set to limit the maximum speed of both the power turbine and the gas generator.

In addition, an overspeed trip is fitted to the power turbine which operates quite independently of the governors and will shut the engine down very rapidly in the event of the permissible speed being exceeded. This overspeed trip has been tested many times at full power by driving a dynamometer through shear couplings and the power has been increased until a sudden failure of the couplings occurred so as to give the worst possible conditions for an overspeed.

Fig. 7 shows diagrammatically the engine and reverse gear control system. The reverse gear and throttle are controlled from a single lever mounted on the bridge. Forward movement of this lever engages the "Ahead" clutch and selects the desired power, depending upon how far forward it is placed. As soon as the clutch is engaged the engine throttle is automatically opened to the position required. As the throttle is opened by servo-oil taken from the appropriate clutch it cannot be opened until the oil pressure has built up in the clutch. In addition, in the event of the servo-oil pressure falling, the throttle will close before the pressure has dropped to a point at which the clutch would slip. Slow opening of the throttle is provided for by a restrictor in the oil feed, but this restrictor is bypassed by a non-return valve in the event of oil pressure failure, to give very rapid closing.

A separate lever is provided at the engineer's position, by which the slow running setting can be adjusted if required, but engagement of the gear and higher throttle settings can only be obtained through the hydraulically controlled mechanism. The detail design and manufacture of this control have been carried out by Lockheed's Aircraft Hydraulic Division.

AIR INTAKE

In the early stages of the project a great deal of thought and consideration was given by the Admiralty, Vospers Ltd., and the author's company to the engine air intake arrangement. Finally, Mr. Revans of the Department of Naval Construction suggested the arrangement which was eventually adopted. In this arrangement a large fibreglass hood is built abaft the bridge structure and serves both as a crew shelter and a guard to prevent the direct entry of heavy spray into the air intake proper.

A model of the vessel including this intake arrangement was tested in a wind tunnel at the National Physical Laboratory, so that the effect of eddies in drawing in spray could be observed.

In order to silence the compressor intake noise, fibreglass packed splitters are provided in the intake and it occurred to the author that with a little development it might be possible to make these splitters serve also as water separators. Promising results were obtained on small-scale model tests and following this the full-scale rig representing the boat's intake but reduced in width by one-third was manufactured and tested.

Fig. 8 illustrates the splitters, which are streamlined at the trailing edge and slope aft. This streamlining produces a thick and low velocity boundary layer which encourages the water to run down from the splitters rather than be blown off into the air stream. After some experimental work, effective drains were produced at the bottom of the intake to drain off the water. Fig. 9 shows the results attained on the small scale rig.

On most tests the difference between the quantity of water injected and that collected in the drains could be largely accounted for by evaporation and the apparent efficiency therefore varied with the atmospheric humidity. Tests have been made on the full scale rig with the equivalent of up to 3 tons of water per hour per engine.

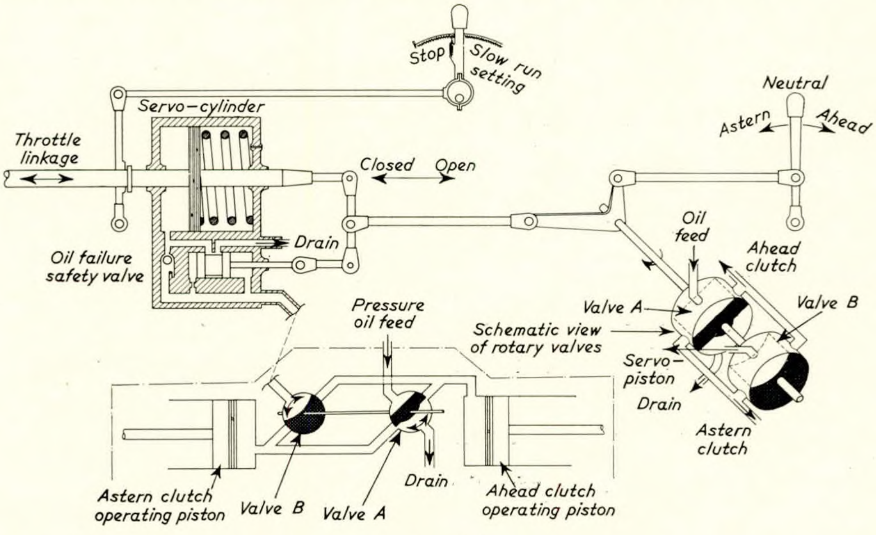


FIG. 7—*Throttle control diagram*

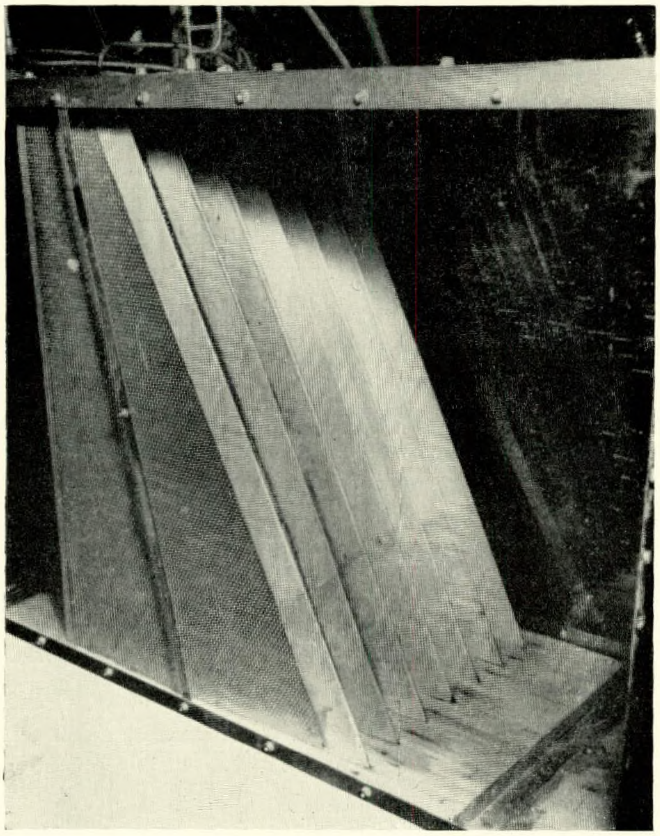


FIG. 8—*Splitters for intake rig*

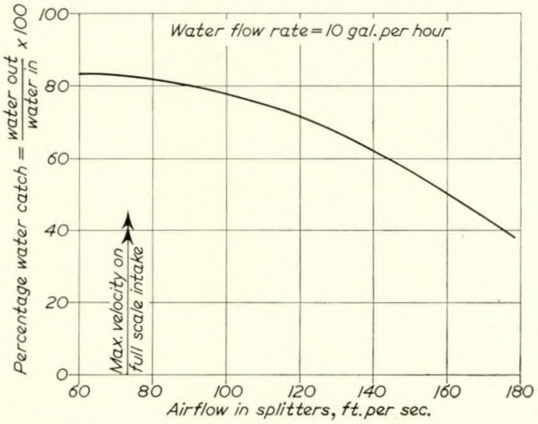


FIG. 9—*Results of water catchment tests*

EXHAUST SYSTEM

Although the use of a transom exhaust has many advantages, including a gain of nearly one knot in top speed due to exhaust thrust, the author originally felt somewhat apprehensive about the risk of water entering the exhaust pipe under low speed and very low power conditions.

Observations were made in representative sea conditions on a small Vosper-built launch with similar hull lines to the *Brave* Class, with reassuring results.

Calculations and practical tests have shown that with the engines running above idling power it is impossible for water to enter the exhaust pipe which terminates some way inside the exhaust pipe shroud. To prevent water in any serious quantity entering the shroud with the engines stopped, flap valves are provided. These valves are partially opened before starting the engine and provide protection against the entry of water at low powers. At powers in excess of about 700 s.h.p. they are automatically opened fully by a pneumatic jack operated by compressor air pressure. The control which turns on the air also operates the compressor blow-off valves, which are a standard feature of the aircraft and marine engines and which are closed at the same engine conditions.

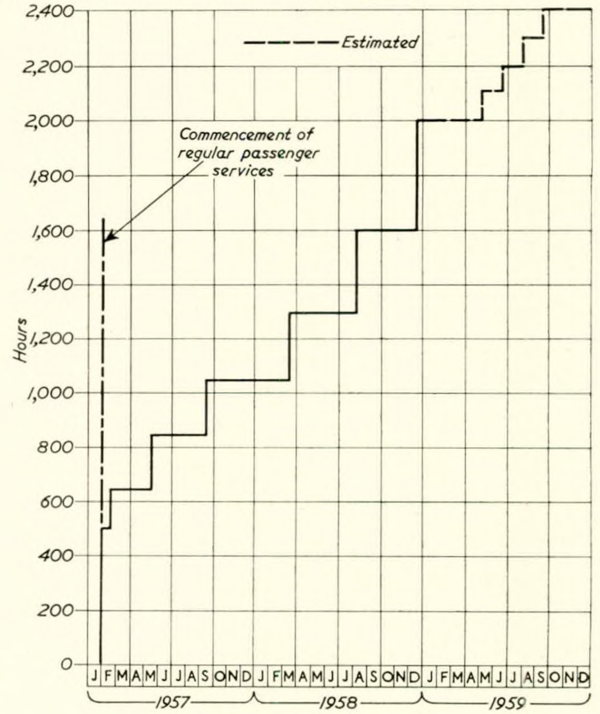


FIG. 10—*Aircraft engine overhaul life*

ENGINE PERFORMANCE

Engine performance must be related to the life required between overhauls and the general operating conditions. The rating which is used on the *Brave* Class was specified and agreed some five years ago and was intended to be conservative. In the light of some 60,000 hr. of bench testing on

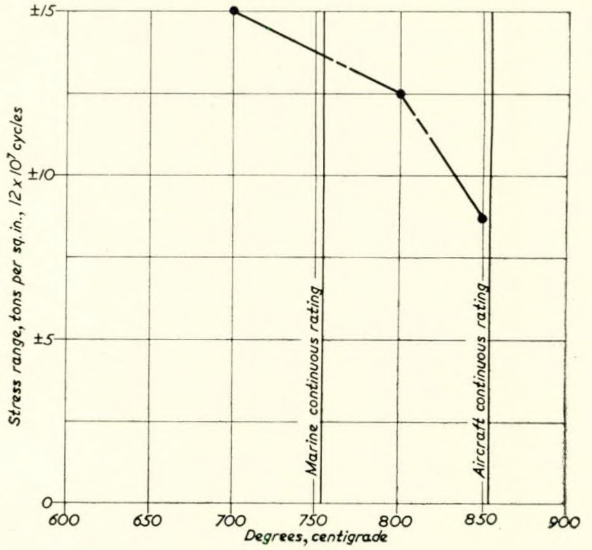


FIG. 11—*Comparison of operating temperatures and effect on fatigue strength of the turbine blade materials*

aircraft engines and over 1,840 hr. on marine engines, not to mention over half a million hr. in airline service, this rating still seems to be conservative. Fig. 10 shows the life between overhauls of the aircraft engine in B.O.A.C. service. Engine cowlings remain closed for 100 hr., after which they are opened for examination of filters and routine inspection. No other servicing is carried out between overhauls except for a scheduled change of fuel pumps carried out at half-time.

Fig. 11 shows the effect of temperature on the fatigue strength of turbine blade material and on this curve is also shown the turbine entry temperature at the continuous rating for marine and aircraft engines running over 2,000 hr. between overhauls, and this gives an indication of the extent to which the marine engine is derated. If creep stress were taken as the criterion, as is often done, the apparent derating would be very much greater, but it is not considered that creep strength is a valid criterion for engines of anything but the shortest lives. Figs. 12 and 13 show the performance of the Proteus 1250 engines used in *Brave Borderer*. The later Proteus 1260 gives an increase in power of 8 per cent with no increase in turbine entry temperature and a further development has permitted a further increase in power to 4,000 s.h.p. at the same temperature with a specific fuel consumption of 0·59 lb. s.h.p./hr.

The use of higher temperatures made possible by improved materials has improved the power to 4,250 s.h.p. and reduced the consumption to 0·575 lb/s.h.p/hr.

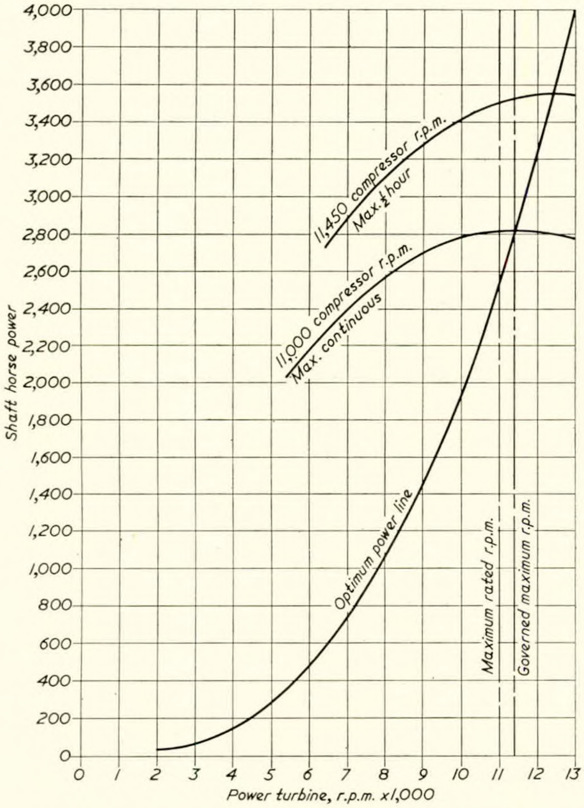


FIG. 12—*Proteus 1,250-marine engine performance curve: horse power*

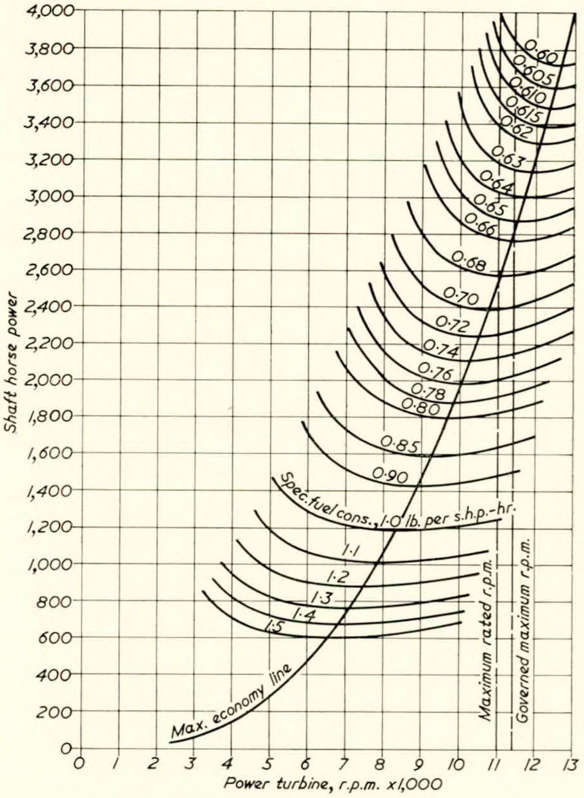


FIG. 13—*Performance curve: fuel consumption Proteus 1,250-marine engine*

The fuel consumption is, of course, still considerably greater than that of a Diesel engine but for many purposes and certainly for fast patrol boats this is far outweighed by the reduction in machinery weight. Fig. 14 shows a comparison of the fuel consumption per hour on the Proteus 1260 engine and an assumed Diesel engine of 3,800 h.p., giving the same specific fuel consumption as the lightest known marine Diesel engine. In both cases the consumption has been taken on a propeller law basis, assuming power to vary as N^2. It will be noted that the difference in consumption is substantially independent of the power actually used and is about 660 lb. per hr. The difference in installed weight between the Proteus with a reverse reduction gear and Vee-drive and a Diesel engine having the power/weight ratio of the lightest known Diesel engine is approximately 6·2 tons, and this difference in weight is equivalent to the difference in fuel used in about 21 hr.

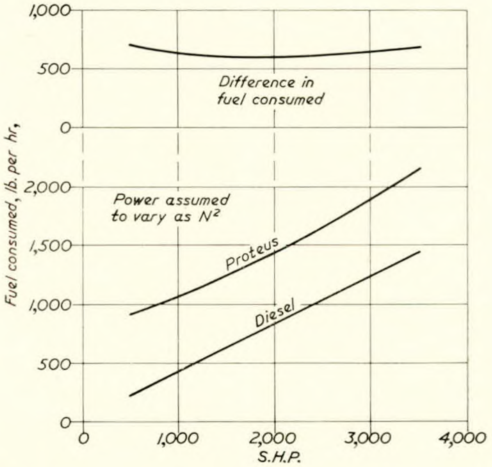
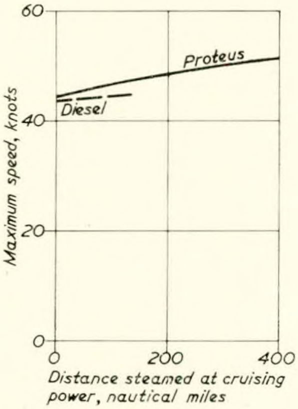


FIG. 14—*Comparison of Diesel and Proteus fuel consumption*

Fig. 15 shows the estimated performance of a practical high speed vessel with two Proteus engines and a vessel with the same total weight of machinery and fuel, using Diesel engines of equal power. It will be seen that the Diesel engined vessel cannot carry a practical quantity of fuel and it would be necessary either to have a larger vessel or have lower power and lighter Diesel engines and accept the lower speed in order to achieve a practical range. The small difference in speed between a Proteus and a Diesel engined vessel at the same power at the start of the sortie is due to exhaust thrust. It will be noted that owing to the higher fuel consumption the maximum speed available with the Proteus engine increases much more rapidly with distance steamed than in the case of the Diesel engine.



	Tons
2 Proteus and gearing	5·8
Fuel	15·8
	21·6
2 Diesels and gearing	18·2
Fuel	3·4
	21·6

FIG. 15—*Comparison of performances in high speed craft*

If it is assumed that the vessel can be overloaded at the beginning of the sortie to increase the range, the Diesel engine will have the advantage that a given increase in fuel load will increase the range by about 50 per cent more than it would on the gas turbine version. It will however have to suffer the burden of this increased load for longer and furthermore the effect on performance will be far greater.

This is due to the greater flexibility of a gas turbine and is illustrated in Fig. 16. Dependent on the hull characteristics, an increase in hull resistance which will produce a power drop of 2 per cent with a gas turbine will give a power drop of 28 per cent with a Diesel engine. With a normal hull form the effect will be less, while with a hydrofoil craft it may be far greater.

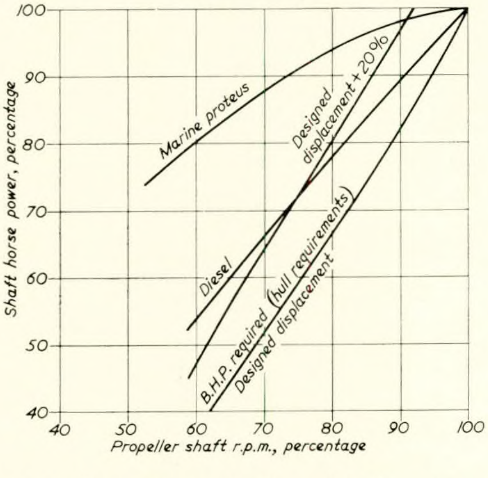


FIG. 16—*Comparison of effect of hull resistance*

For a Naval vessel it is worth noting that if one engine is put out of action the loss in speed will be much less with gas turbines than with Diesel engines.

One of the alleged disadvantages of the gas turbine is the greater loss in power due to high intake temperatures. However, if the Diesel engine is exhaust temperature limited, the gas turbine is in reality at no disadvantage and, as can be seen from Fig. 17, an 8 per cent derating of the gas turbine will have about the same effect on boat performance as a 4 per cent derating on a Diesel engine.

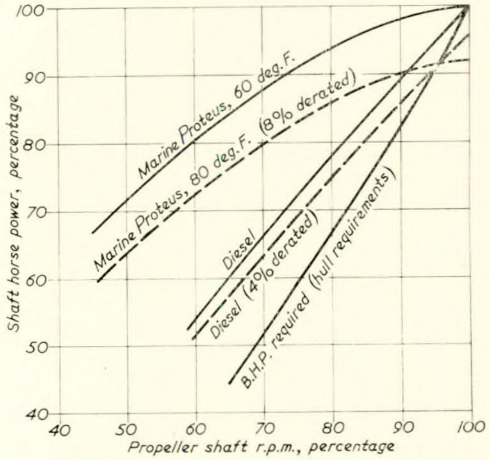


FIG. 17—*Comparison of effect of ambient temperatures*

Conversely, the propeller for a gas turbine can be designed to take advantage of the increased power available at low temperatures without seriously compromising the performance at high temperatures.

All this discussion of comparative performance must not lead one to suppose that the advantage of the gas turbine lies mainly in this direction. In the author's opinion the greatest advantage lies in the simplicity, reliability and ease of maintenance of the gas turbine. This opinion seems to be shared by all who have had experience of gas turbines whether it be in marine, aircraft or industrial applications.

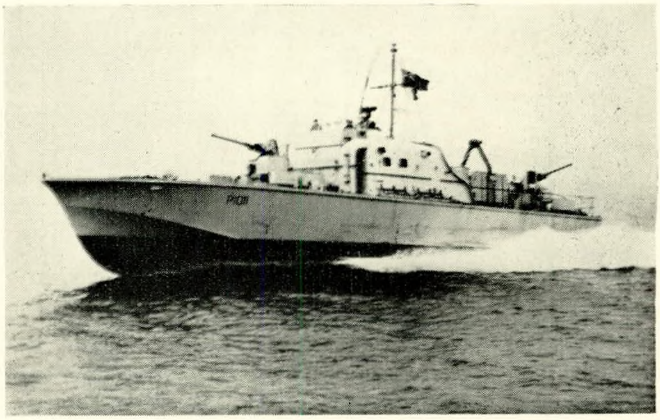


FIG. 18—*The 'Brave Borderer' at over 50 knots*

SEA TRIALS

Fig. 18 shows *Brave Borderer* on trials at a speed of over 50 knots. This speed was attained on the second day's trial and had it not been for the reversed assembly of a non-return valve in the fuel system of one engine (for which the author's company was responsible and which limited the power on this engine) this speed would have been achieved on the first day. The attainment of this fine performance with no preliminary tuning up reflects the greatest credit on the builders and designers. Particular mention must be made of the propellers, which exactly matched the hull and engine characteristics. Such matching is less critical in a turbine than in a reciprocating engined vessel and the designer has little to lose by designing for an optimistic performance.

Engine starting which had been faultless on the test bed proved at first embarrassingly uncertain on the boat and there is possibly a moral lesson in this. The engines are electrically started from current supplied by Rover Gas Generators Ltd., and, in order to ensure that there should be no hitch at sea, arrangements were made to operate a Rover unit for starting tests at Bristol. The author had feared that the sudden loads thrown on the Rover units at starting might cause a reduction in speed and voltage and result in sluggish starting. The trials which were carried out showed that this was far from being the case and in fact the rate of engine cranking and acceleration was better than that previously attained. The testers reported, however, that during these trials there appeared to be a little more delay in obtaining a light-up. It was not, however, considered that this could have been due to the Rover units and the warning was not heeded.

When the engines were installed in the vessel this delay in lighting up became more noticeable and in some instances engines would light up and then almost immediately flame out. Investigation showed that owing to the excellent response of the Rover units, and some overcompounding of the generators, the voltage obtained at the engine starter was excessive and gave too high an initial rate of cranking, which tended to blow out the flame. This unexpected defect was quickly corrected by putting a permanent resistance in series with the starters.

In the early bench development it was found advantageous to warm the fuel so as to improve the combustion at low powers and it was found that this could be achieved by the use of fuel cooled oil coolers which satisfactorily dealt with all the engine oil cooling. However, on the sea trials it was found that this method of cooling was inadequate at high powers. This difference is partly due to the inclined angle of the engine in the vessels and partly to the small volume of air flowing over the reduction gears. A small modification has been made which improved the oil drainage from the reduction gears in the inclined attitude and some improvement in the efficiency of the fuel cooled oil coolers has been made, but to provide an adequate margin at high powers it has nevertheless been necessary to supplement the fuel cooled oil coolers by a small amount of water cooling. Fortunately, it has proved possible to do this without introducing a water circulating pump or making additional holes in the ship's skin. This has been achieved by adding a short section to the oil cooler provided for the reverse reduction gears. The modified cooler is shown in Fig. 19.

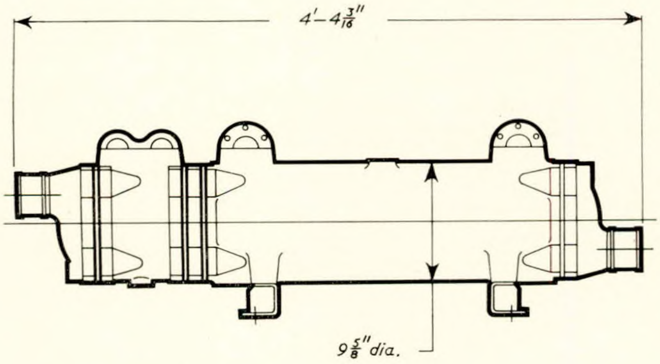


FIG. 19—*Combined gearbox and engine oil cooler*

These are the only troubles which have been experienced so far with the engines or their installation. It is possible that there has been provided a rather unnecessary degree of heat insulation over the exhaust pipe and that the degree of intake silencing has been rather luxurious. There is room for some weight saving in both the heat and sound insulation.

The general sound level on the vessel has caused great satisfaction and on the bridge one is not conscious of any engine noise. Such noise as there is on deck appears to be mainly gear noise.

In the forward engine room, with over 10,000 h.p. being transmitted and with a Rover gas turbine engine running, some noise is to be expected, but this noise level does not prevent conversation amongst those experienced in engine room conditions or with the operation of an intercommunicating system between the engine room, bridge and the engineer's station.

Engine handling from the bridge has proved simple and popular and the minimum speed available is more than adequate.

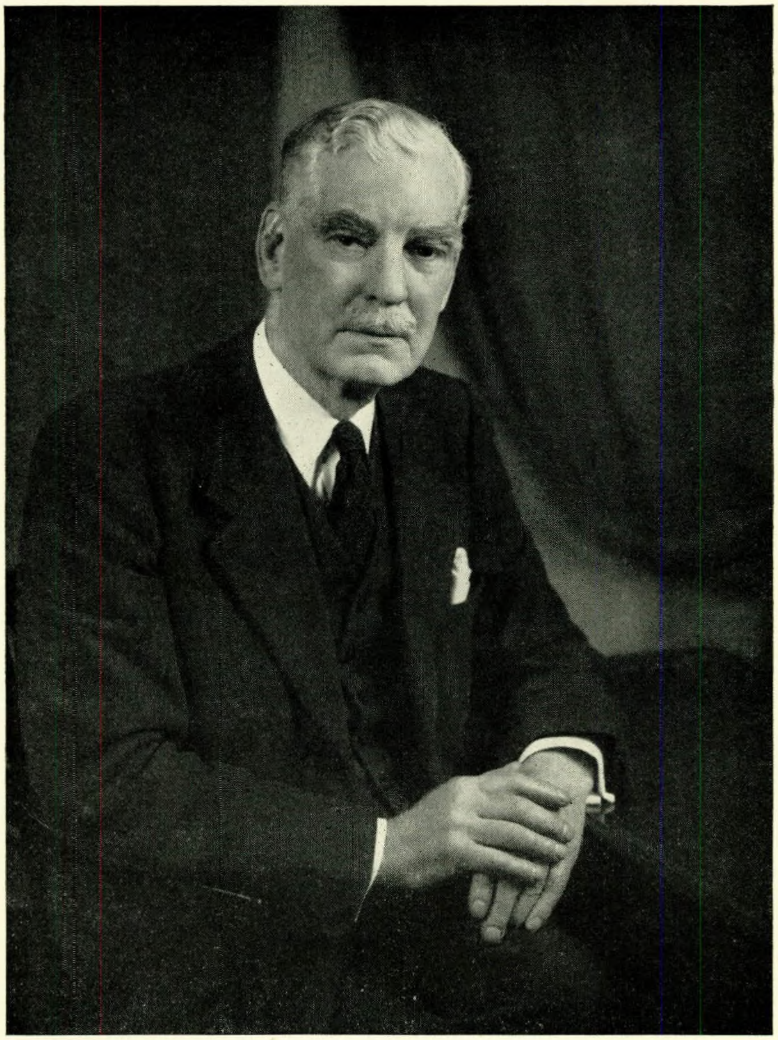
On one occasion a failure of the reverse gear hydraulic oil pressure occurred and the automatic control shut the engine down to idling speed smoothly and effectively.

The transom exhaust has worked out well in practice.

Rough weather trials have demonstrated the effectiveness of the air intake arrangements. In 20 min. some two gallons of water were collected in the drain from the first row of splitters but no water was collected from the second row or from any of the other drains, indicating that the first row had been fully effective.

ACKNOWLEDGEMENT

The author has been indeed fortunate, not only in the help and support he has had from his colleagues and staff, but particularly in the enthusiastic support and valuable advice he has received from the Admiralty and from Vosper Ltd.



SIR WILLIAM WALLACE, C.B.E., LL.D., F.R.S.E.

SIR WILLIAM WALLACE, C.B.E., LL.D., F.R.S.E.

Sir William Wallace was born in Leicester in 1881, the son of Matthew Wallace of Paisley, and was educated at Paisley Grammar School and later at Anderson College, Glasgow.

He received his practical training with Messrs. Bow McLachlan and Company of Paisley; then he went to sea and obtained a First Class Board of Trade Certificate, and sailed as chief engineer with the British and Burmese Steam Navigation Company.

He came ashore in 1911 and joined Messrs. Brown Brothers as a draughtsman. He became Managing Director in 1917 and Chairman in 1946. During this period he took out many patents on ship steering gear and in 1937 the first "Denny-Brown" Ship Stabilizer was fitted to the *Isle of Sark* to his design, and was the forerunner of many further installations, both merchant and naval. He retired as Managing Director in January 1958 and as Chairman in March 1959.

He is also a director of Messrs. Alexander Cowan and Sons, the North British Rubber Co., Ltd., William Beardmore and Co., Ltd., and Henry Robb and Co., Ltd.

In 1954 the Society of Engineers presented to Sir William the Churchill Gold Medal, which is awarded biennially for "outstanding invention and development in engineering". He received an Honorary Degree as Doctor of Law from Edinburgh University in 1956. He is a Past President of the Institution of Engineers and Shipbuilders in Scotland, a Member of Council of the Institution of Naval Architects, and a Member of the Institutions of Mechanical Engineers and the North East Coast Institution of Engineers and Shipbuilders.

Sir William has held many other honorary appointments, industrial, civil, educational and charitable. He is a former President and now a Trustee of the Engineering and Allied Employers' National Federation and Chairman of their Finance Committee; an Honorary Vice-President of the Scottish Engineering Employers' Association; Director and Ex-President of the Edinburgh Chamber of Commerce and Manufacturers. He is a Commissioner of Income Tax of the Ancient Royalty of Edinburgh; and a Member of Panel of the Board of Referees (Finance (No. 2) Act, 1915) Income Tax Act, 1918, and Finance Acts, 1922, 1927. He is a Member of the Board of Governors of Leith Nautical College. He is a Trustee of the William Brown Nimmo Charitable Trust, William Hunter's Trust, and the John Wilson Bequest Trust.

Sir William belongs to the Scottish Conservative Club and the University Club in Edinburgh, to the Conservative Club in Glasgow, and to the Royal Automobile Club in London. He is a member of the Honourable Company of Edinburgh Golfers, Muirfield, and is a former captain of the Bruntsfield Links Golfing Society.