Operation of a Marine Gas Turbine Under Sea Conditions

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The paper describes in detail the results obtained over a period of two years with the first gas turbine to be used for the propulsion of a merchant ship.

After giving the reasons for installing the turbine and briefly describing the machinery layout in the ship, the authors outline the general performance of the turbine set under varying sea and atmospheric conditions.

Each component is then dealt with separately, the methods adopted to maintain each in an efficient condition and the effect of salt in sea air upon the compressors, and fuel ash upon turbine blading, are described.

Particulars are given of all mechanical defects encountered, together with a detailed description of the nature and extent of blade corrosion.

The paper contains information regarding the heat-resisting properties of special steels employed and of the composition of deposits found in the h.p. turbine and heat exchanger.

Mention is made of the steps taken to adjust the length and shape of the flame in order to avoid parts of the combustion equipment burning away.

The importance of grit-free fuel is stressed and the measures taken to ensure this are given, as well as the results obtained in burning fuels ranging in viscosity from 40 to 1,500 seconds Redwood I at 100 deg. F.

PURPOSE OF THE "AURIS" EXPERIMENT

The authors' interest in gas turbines for ship propulsion began during the recent World War when it was felt that in the present age of progress the heavy, complicated Diesel engine would sooner or later have to make way for a power installation of greater simplicity, and of less weight for a given power developed. Also it appeared at that time, and nothing has happened since to materially alter the view, that whilst its weight per unit power developed might be reduced, the Diesel engine had, as regards thermal efficiency, reached its limit. As it was the most thermally efficient power producer that could be entrusted with the propulsion of a ship, many were inclined to be rather complacent, until they began to think not of the quantity of heat in the fuel converted into useful work, but the quantity not so used. As is well known, this represents between 60 and 70 per cent.

It was also realized that the end of the war would see changes in matters relating to the maintenance of ships' machinery. The time required to carry out routine overhauls would increase, and the only way to avoid reducing the earning capacity of ships to the point when the principal incentive to the investment of money in shipping would be considerably reduced or maybe eliminated, would be to adopt machinery which would either require less overhauling or could be overhauled in a shorter time and at less cost.

The capital outlay required to build ships has risen so much during the last decade that it becomes more necessary than ever to reduce the off-hire periods, particularly as the amount of capital not represented by the machinery, lying idle during such periods, is of the order of 60 per cent for cargo ships and may be as much as 80 per cent of the total in the case of passenger ships. Unless a ship's hull is seriously damaged or badly wasted due to age and requires extensive repairs, the bulk of the capital invested is, therefore, non-productive during the time the machinery is having attention.

Also, it was thought that, in view of the enormous progress made since the days of sail, it should be possible, and would in the future be necessary, to handle the cargo with the power plant used to drive the ship.

It is an elementary law in ship economics that the larger the amount of money invested in a ship the shorter should be the periods in port. The only way to achieve this is to step up the rate of loading and discharging cargoes, and this in turn requires the production of more auxiliary power. More power of this kind in a ship means greater initial outlay, less cargo carried for given dimensions, and higher maintenance costs.

In the case of steamships, part of the propelling plant can be used for handling cargo, but not in the most economical manner. Moreover, the wisdom of using main boilers continuously is questionable. In such installations the time in port is, and should be, used for cleaning and maintenance if the boilers are to be worked at maximum efficiency at sea. In motor ships where the propelling engine is directly coupled to the propeller shaft, not only must the power output of the whole of the cargo handling machinery be increased, but the whole of it remains idle for a great proportion of the ship's life. In the case of oil tankers this may be as high as 92 per cent.

It is realized that in designing ships' machinery of orthodox type it is possible to make use of part of the propelling power in port and part of the cargo equipment at sea, but the authors are of the opinion that the time has come to supply all cargo requirements with power produced by the propelling machinery.

The only way to achieve this is either to split up the propelling power into a number of small units, which in addition to the one outlined has other advantages, or adopt a power producer of simple construction such as the gas turbine, which

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has a minimum number of parts subject to wear and tear, and which, therefore, does not need to be shut down in port for maintenance or repair.

In a modern oil tanker the power to meet cargo requirements is about 20 per cent of the propelling power and, if the machinery comprises steam turbines, electrical transmission must be employed if the turbines are to be used for cargo. In the case of gas turbines employing the two shaft principle, the transmission may be either electrical or mechanical, and as the transmission losses are some 3 per cent less in the latter, a propelling installation which can employ this form of transmission is to be preferred.

The thermal efficiency of the gas turbine at the present time falls short of that of the Diesel engine, but whereas that of the latter is unlikely to improve to any appreciable extent, the authors see no reason why that of the gas turbine should not surpass that of the Diesel without sacrificing the strong position held in respect of simplicity in construction and reduced maintenance. In the light of experience gained during recent years it is felt that to aim at a thermal efficiency of 45 per cent is not too ambitious.

The development of a satisfactory form of blade cooling has yet to be achieved, but so great is the incentive in terms of improved thermal efficiency which will result from the consequent use of higher gas inlet temperatures, it is felt that success in this direction cannot be far away. For marine installations the use of air as the cooling medium is likely to be preferable to that of water for reasons of simplicity and lower maintenance.

The 1,200 b.h.p. open cycle non-reversible British Thomson-Houston gas turbine set installed in the *Auris* is essentially experimental. It was designed for the express purpose of determining the problems likely to arise due to long

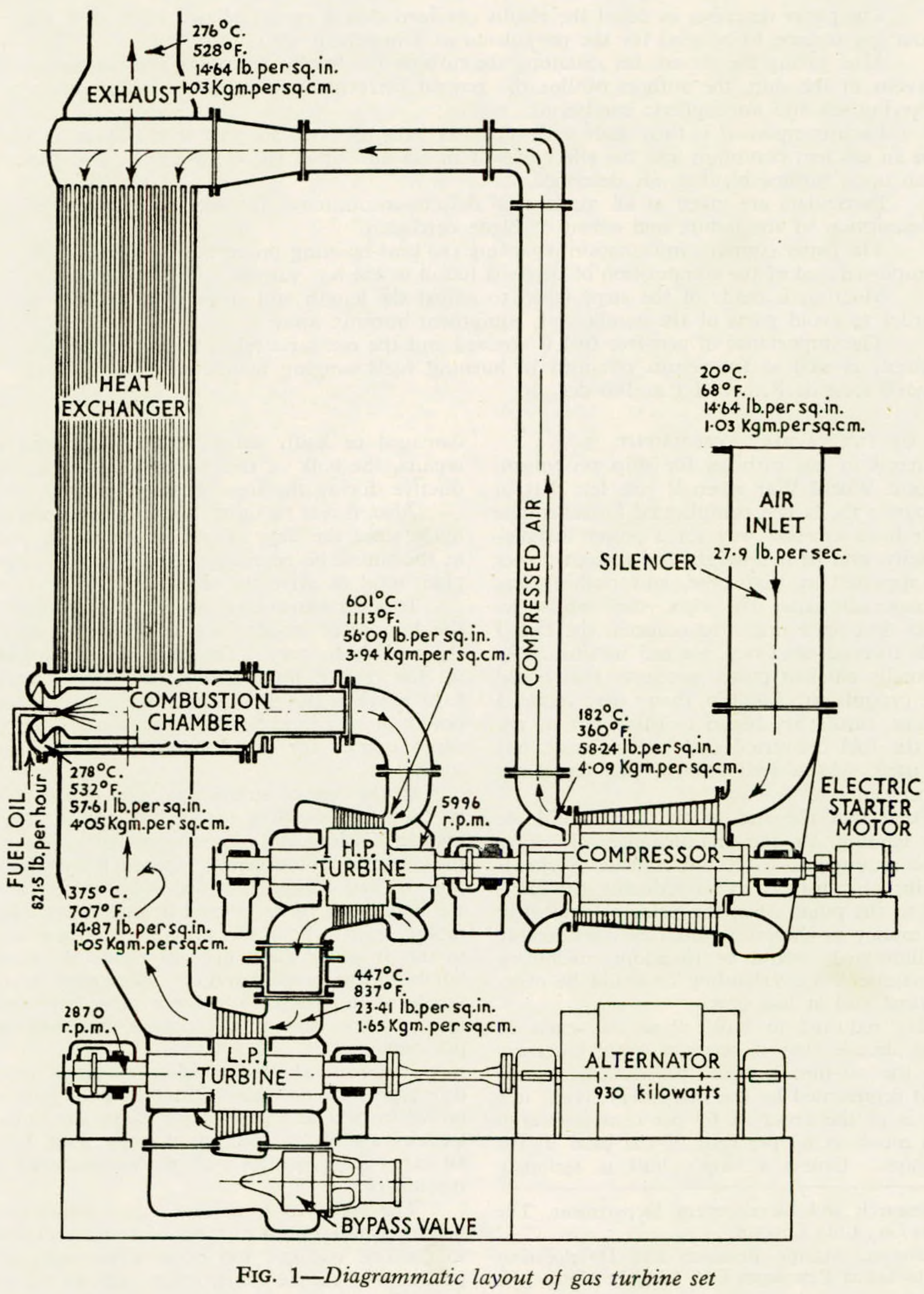

FIG. 1—*Diagrammatic layout of gas turbine set*

continuous operation, varying conditions of atmosphere and sea and the burning of the heavier grades of liquid fuel.

Before being installed in the ship the set underwent shop trials for 679 hours, but when testing such an engine ashore the conditions can be too carefully controlled and long continuous runs are not always possible. Moreover, testing ashore is invariably wasteful as the load is absorbed by a dynamometer. In a ship, not only do actual operating conditions prevail, but the power developed is usefully employed and can be varied as desired.

In addition to testing the set at sea, it was essential to continue combustion experiments with a view to increasing the life of the combustion equipment and to correlate changes in combustion with deposits. This work represents a major programme and will continue for some time yet.

The *Auris* was originally propelled by four 1,105 b.h.p. at 375 r.p.m. Diesel engines driving A.C. alternators which supplied current to a synchronous motor directly connected to the ship's propeller shaft. This form of propulsion was adopted for two main reasons, the first being to obtain experience with the burning of high viscosity fuels in moderately high speed Diesel engines, and secondly to permit installation of the turbine, then being constructed, at a later date. Also, it was desired to try out A.C. electrical current for all ship's services under sea conditions.

The question of replacing two Diesel engines by a gas turbine set of 2,400 b.h.p. was considered, but it had already been decided to make the turbine suitable for ahead running only, in order to keep down initial costs. Moreover, it was doubtful if two Diesels would be sufficient for reliable manœuvring of the ship. One Diesel only was therefore replaced by a 1,200 b.h.p. turbine set.

As the gas turbine set was to represent 25 per cent only of the total propelling power, the safety of the ship would not be jeopardized in the event of a breakdown. Also, it sometimes happens in matters of this kind that if the mobility of the ship depends upon the experimental engine, all evidence of the cause of trouble encountered is removed by the engineers in their eagerness to get the ship underway again.

GENERAL DESCRIPTION

The removal of one of the Diesel engines made available a space which, though large enough to accommodate a gas turbine of the required power, placed certain restrictions on its design; in particular, the narrow width dictated the choice of an arrangament in which the h.p. turbine and compressor were mounted vertically above the l.p. turbine and alternator. Intercooling would not in any case have been adopted owing to the small mass flow, but the heat exchanger had to be limited in size.

The Diesel engine, which was to be replaced by the gas turbine set, was provided with a completely independent fuel system which incorporated centrifugal purifying equipment of the type used so successfully on motorships burning high viscosity fuels. Such provision enabled firstly one Diesel engine and subsequently the gas turbine to be operated on fuels of different characteristics, or fuels specially treated, whilst the remainder of the installation operated on normal grades.

Fig. 1 shows the air and gas paths through the different components of the gas turbine set and the designed pressures and temperatures. It also indicates approximately their relative positions in the ship.

Atmospheric air is drawn into the axial compressor, is compressed and is then preheated by passing downwards inside the tubes of the vertical heat exchanger. The hot exhaust gas from the l.p. turbine flowing upwards outside the tubes is thereby cooled before being expelled to the atmosphere.

The preheated compressed air from the heat exchanger is led to the twin combustion chambers situated in the heat exchanger outlet drums. Only about a fifth of the air supplied by the compressor is needed for combustion of the fuel, which takes place in the refractory lined primary zone and which results in temperatures of 3,000 deg. F. or more. The remaining four-fifths are led into the mixing zone in order to cool the gases to 1,200 deg. F., the designed inlet temperature of the h.p. turbine. The h.p. turbine is coupled to the compressor, which absorbs the whole of its power output.

A short straight vertical duct leads the exhaust gas from the h.p. turbine to the l.p. turbine, which is coupled to the alternator and develops 1,200 b.h.p. or 860 kW. at the alternator terminals. From the l.p. turbine exhaust the gas flows upwards through the heat exchanger, as mentioned above, and thence to the atmosphere.

The set is designed to produce 1,200 b.h.p. at the l.p. turbine coupling when working in an ambient air temperature of 68 deg. F. (20 deg. C.), with a maximum h.p. turbine gas inlet temperature of 1,200 deg. F. (650 deg. C.) and a pressure of 47lb. per sq. in. gauge. The designed speed of the h.p. turbine/compressor shaft is 5,750 r.p.m., and that of the l.p. turbine/alternator shaft 3,000 r.p.m.

The h.p. turbine is set in motion by means of a 50 h.p. D.C. electric motor. To facilitate starting, a bypass valve is provided through which the gas from the h.p. turbine may escape to the atmosphere via the heat exchanger without having to pass through the l.p. turbine. By keeping the bypass valve open during the starting period the back pressure on the h.p. turbine is reduced, and the power demand and the time required for starting are also less.

Each combustion chamber is provided with two fuel burners, one for starting-up and one for normal running. When an h.p. turbine/compressor shaft speed of about 1,200 r.p.m. is reached, fuel is admitted to the combustion chambers through the starting-up burners, which have built-in ignitors, and the

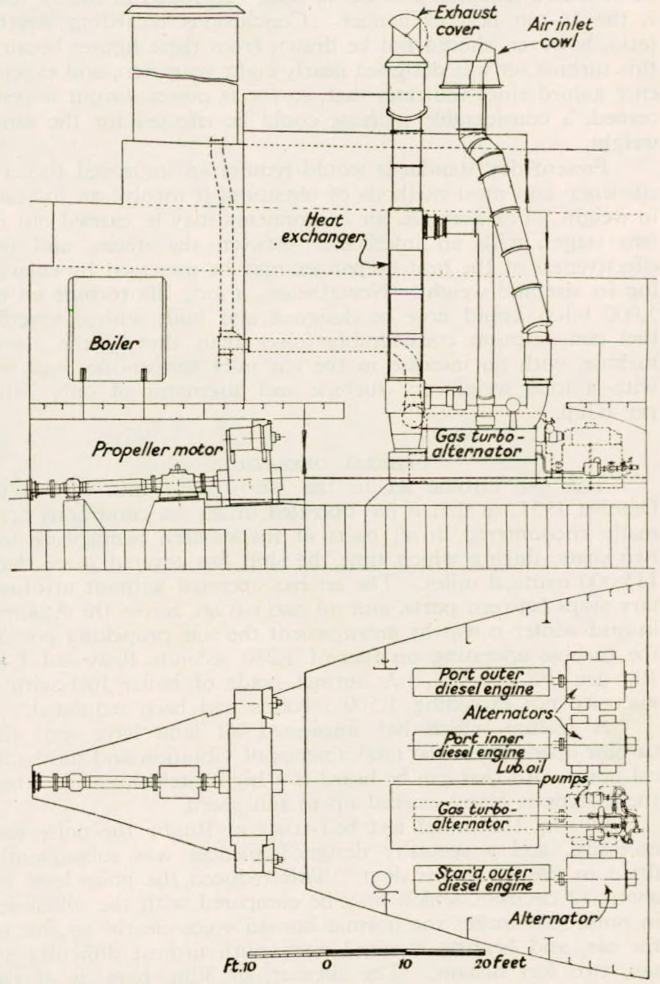

FIG. 4—*Arrangement of machinery; space originally occupied by starboard inner Diesel alternator shown dotted*

turbine then assists in driving the compressor. When the h.p. turbine/compressor shaft reaches a speed of about 1,800 r.p.m., the main fuel burners are brought into use and the bypass valve closed when output from the l.p. turbine is required.

The bypass valve also acts as a safety device for, if the l.p. turbine shaft should overspeed through sudden removal of the electrical load or for any other reason, a trip operates and the fuel supply is automatically shut off and the bypass valve opened.

Fig. 2 (Plate 1) is a photograph of a one-eighth scale model of the turbine set, while Fig. 3 (Plate 1) shows a close-up view of the h.p. turbine/compressor components. In Fig. 2 will be noted the deep fabricated frame which supports the different components. This allows the set to be lifted, with the exception of the heat exchanger, as one piece.

The seating for the turbine was prepared when the ship was built in 1948. Due to the alternator being contained within the fabricated steel frame, the length of the set is less than that of the Diesel engine it replaced, but the height is greater. An outline of the turbine set superimposed on the original layout is shown in Fig. 4.

A notable feature of this gas turbine set is its simplicity, operating as it does on the simplest possible cycle. It is provided with independent lubricating oil and fuel oil systems. No other auxiliaries are necessary except to supply cooling water for the alternator and lubricating oil cooler. To keep duct losses to a minimum the exhaust is led through the skylight to atmosphere a few feet abaft and above the air intake.

The total weight of the set and its alternator is 55 tons (102·5lb. per b.h.p.), the weight of the Diesel engine and alternator which it replaced being 43 tons. Included in the 55 tons is the 16-ton heat exchanger. Conclusions regarding weight ratio, however, should not be drawn from these figures because this turbine set was designed nearly eight years ago, and experience gained since indicates that, so far as power output is concerned, a considerable increase could be effected for the same weight.

Present-day standards would require an improved thermal efficiency and most methods of obtaining it involve an increase in weight. For example, air compression may be carried out in two stages, with an intercooler between the stages, and the effectiveness of the heat exchanger may be increased by enlarging its size and weight. Nevertheless, a long life turbine set of 5,000 b.h.p. could now be designed and built with a specific fuel consumption considerably lower than that of the *Auris* turbine, with no increase in the gas inlet temperature and yet with a total weight for turbine and alternator of only 74lb. per b.h.p.

GENERAL OPERATION

The gas turbine set in the *Auris* went into service in October 1951, so that it has operated under sea conditions normally encountered in all parts of the western hemisphere for two years, during which time the ship has covered more than 115,000 nautical miles. The set has operated without involuntary stops between ports, and on one voyage across the Atlantic in mid-winter it was by arrangement the sole propelling power, the turbine operating on fuel of 1,230 seconds Redwood I at 100 deg. F. viscosity. A normal grade of boiler fuel with a viscosity not exceeding 1,500 seconds had been requested.

A feature which has impressed all who have seen the turbine operating is the total absence of vibration and mechanical noise. All that can be heard is a high pitched whistle when the turbine is being worked up to full speed.

During the initial test bed trials at Rugby the noise was excessive, and a specially designed silencer was subsequently fitted in the air intake duct. This reduced the noise level by about 12 decibels, which may be compared with the difference in noise that makes the normal human voice clearly audible to the ear, and hearing a raised voice with utmost difficulty at, say, two feet distant. The silencer, of 30in. bore, is of the straight through type, packed with vegetable fibre and made in five units. The total weight is 2·2 tons.

No major renewals have been necessary and the cleaning of the air compressor and heat exchanger has become a routine operation which can be accomplished well within the time the ship is loading or discharging its 12,000 tons of bulk oil cargo. The minor renewals required and mechanical difficulties encountered are described below.

Although complete opening-up has been limited to the h.p. turbine, a careful record of the condition of the other components has been kept, the condition being ascertained by means of the introscope and by careful analysis of the various temperatures, pressures and other operating particulars. During the ship's routine drydocking prior to the present one, the only work undertaken was recalibration of instruments and pressure testing of the heat exchanger tubes. At the present drydocking, all parts of the set are being opened up and thoroughly examined for distortion, corrosion or other unknown defects, and the blades in the first four stages of the h.p. turbine are being renewed in accordance with arrangements made soon after the set went into service.

During the shop trials and the two years' service which followed, the gas turbine set has operated on load for 11,200 hours and consumed 3,468 tons of fuel. Of this period, 2,800 hours have been on fuels having a viscosity of between 1,200 and 1,500 seconds Redwood I at 100 deg. F. During the remainder of the time, the set has run on normal marine Diesel grades. None of the fuel used has been ash free, the marine Diesel containing up to 0·06 per cent of ash and the boiler fuel up to 0·09 per cent. When all parts are working at their full efficiency, the average fuel consumption per b.h.p. is 0·75lb. In the case of the 8,300 b.h.p. gas turbine set to be installed in the Anglo-Saxon 18,000-ton d.w. tanker now under construction, the thermal efficiency will be not less than 27 per cent and the fuel consumption of the order of 0·53lb. per b.h.p. per hour. This set will operate exclusively on normal grades of boiler fuel.

When the set in the *Auris* was first put into service, the intention was to use Diesel fuel on the first round Atlantic voyage and then change over to more viscous fuel. At the end of the first voyage, however, slight corrosion of the first row of h.p. turbine blades was observed and new blades of greater heat- and corrosion-resisting properties were ordered. The set was then operated on boiler fuel, but when after a time it was learned that the new blades could not be delivered in under eighteen months, the h.p. turbine inlet temperature was restricted to 1,100 deg. F. and the set put back to work on marine Diesel fuel, although there was at that time no evidence to indicate that this grade was less detrimental in this respect. It was nevertheless assumed that it would be, and the change-over was made to avoid the possibility of the set being made temporarily unusable and experiments in other directions interrupted. The new blades are now being fitted and when the ship returns to service the set will be run on normal grades of boiler fuel.

The eight journal bearings and two thrust bearings of the set are pressure lubricated. The lubricating oil system, which is shown diagrammatically in Fig. 5, is provided with two electrically driven rotary pumps, each with a capacity of 50 gallons per minute. A steam reciprocating pump of similar capacity is fitted for emergency purposes. Normally one pump is sufficient for all purposes.

Because of the high rotor speeds, special precautions were taken during the installation in the ship to prevent any injurious matter reaching the bearings. Each pipe was pickled and the ends sealed until the pipe was connected. Flushing oil was then pumped round the system for 45 hours. These precautions have proved worth while, as the rubbing surfaces were in perfect condition when recently inspected and no measurable wear had taken place.

The grade of oil used is Shell Turbo 29 and it will be seen from Fig. 5 that no centrifugal separator is incorporated in the system. Apart from make-up, the original charge of 1,000 gallons is still in service and an analysis made after 10,060 hours in use indicated that it was in practically new condition.

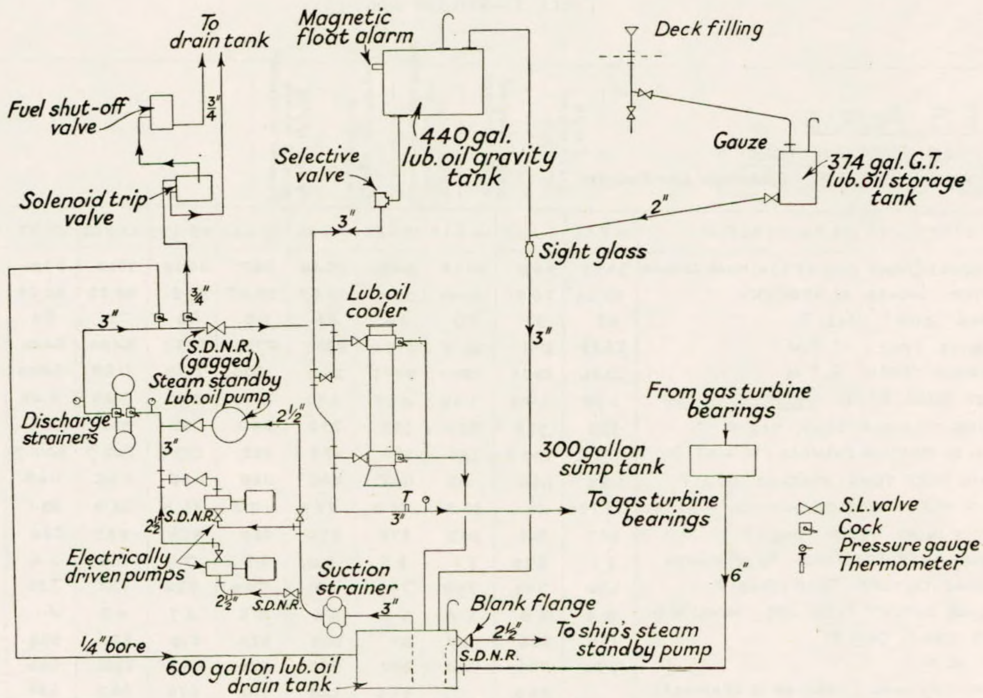

FIG. 5—*Lubricating oil system*

A total of 172 gallons of lubricating oil has been consumed in two years and of this quantity 70 gallons were lost in the first few months due to joints leaking and trouble with the centre pedestal bearing, as described later. The highest temperature attained by the white metal of the bearing in the hottest location was 150 deg. F. with a sea temperature of 83 deg. F.

An important feature in connexion with the bearing lubricating system is the need to continue the supply of oil for some time after the fuel is shut off the set. This results from the very high mechanical efficiency and inertia which causes the shafts to revolve for a considerable time after the motive power is removed, and the great amount of heat stored in the rotors. The lubricating oil pump must, therefore, be independent of the set for its operation.

It takes about 20 minutes for the *Auris* gas turbine rotor shafts to come to rest, so that after only a short run it is necessary to provide facilities for circulating the bearings for at least 30 minutes. After a long run the oil must be circulated for a much longer time in order to carry off the heat in the rotors. The practice in the *Auris* is to circulate the oil for 24 hours and to rotate the shaft by auxiliary power for the first half of that period.

Only three mechanical defects have been experienced. The first was due to a gas leak from the h.p. turbine casing joint as a result of a stud breaking. The hot escaping gases impinged upon the near-by pedestal bearing cap, causing it to distort and permit lubricating oil to leak. As a result the oil was ignited, but the fire was quickly extinguished. As a temporary measure, packing was fitted under the bearing cap but further fires occurred. During the present opening-up the trouble will be overcome by restoring the face of the horizontal joint, thus stopping the gas leak in the casing, and by suitably modifying the pedestal bearing.

The spur gearing of the starting motor failed on one occasion. The turbine set had been shut down to carry out an alteration to the combustion equipment and, upon restarting, the h.p. turbine and compressor were run up to speed in the normal manner. Immediately after the gear wheels were disengaged, however, the jockey wheel seized owing to ineffective lubrication. A torque which forced the jockey wheel into the driving wheel was in consequence applied and the teeth of three wheels were severely damaged. Temporary repairs were carried out by the ship's staff.

The third defect concerns gripping of the l.p. turbine rotor, which has occurred six times. On five of these occasions the gripping occurred on cooling down and took place while the shaft was being rotated by auxiliary power. On the sixth occasion the trouble occurred quite unexpectedly about 30 minutes after starting, in, as far as is known, the usual way.

Whilst on the first five occasions the trouble was definitely due to contractional friction of the labyrinth packing, the cause of the trouble experienced soon after starting has not yet been found. After allowing the set to cool down, it was restarted and no further trouble has been experienced. The most feasible explanation, although there is not yet evidence to prove it, is that the blade tips fouled the casing due to differential expansion occurring under certain unusual temperature conditions.

When the *Auris* is at sea a cable is despatched to the owners every third day, giving the principal operating particulars of the turbine. Table I shows how the cabled information is logged when received; the eleven cables included refer to a voyage from Thameshaven to Oslo, Rotterdam, Iceland and Punta Cardon in Venezuela. The notes at the top of the table have been added to indicate the location of the ship and the periods when the turbine was shut down for adjustments or alterations, chiefly to the combustion equipment.

As explained later, the readings of some of the instruments are known to be inaccurate, and their usefulness lies in revealing departures from normal operation conditions, and for the estimation of changes in component efficiencies rather than their absolute values.

Among points which will be noticed from Table I are the effect on the turbine output of changes in the atmospheric temperature and, in the case of the readings for 25th and 28th June, when only two of the three Diesel engines were in use, the effect of a reduction in the propeller speed and consequently the l.p. turbine speed.

The severest weather in which the turbine has operated occurred early in November 1951 when the ship was crossing the Atlantic with the turbine for the first time. On this occasion the wind was gale force for six days, and the ship pitched and rolled in a manner which caused the Master to make a special log entry. The turbine set operated continuously throughout, although two over-speed cut-outs took place. On each occasion the turbine fuel supply was shut off automatically by the gear provided for the purpose, and the turbine

TABLE I—VOYAGE LOG

D.E.S. "AURIS".
OPERATING PARTICULARS
of GAS TURBINE. (Average per 3 days).

Cargo discharged at Oslo | Cargo loaded at Rotterdam | Turbine shut down twice for burner modifications | Cargo discharged in Iceland | Period of fog during which Turbine shut down | Cargo loaded at Punto Cardon

	CODE LETTER AND ITS EQUIVALENT	31.5.52	6.6.52	10.6.52	13.6.52	19.6.52	23.6.52	25.6.52	28.6.52	1.7.52	4.7.52	7.7.52
A	RUNNING HOURS (ABOVE 4000 RPM) at MEAN READING	3335	3391	3428	3490	3546	3577	3649	3719	3791	3863	3897
B	BAROMETER. INCHES of MERCURY	29·34	29·81	30·03	30·01	29·87	29·97	30·31	30·23	30·20	30·04	30·01
C	AIR INTAKE TEMP: DEG: F	55	52	56	46	46	63	69	79	84	83	82
D	H.P TURBINE SPEED R.P.M	5623	5743	5610	5750	5800	5750	5580	5490	5440	5500	5610
E	L.P TURBINE SPEED R.P.M	2546	2523	2500	2475	2510	2500	2150	2150	2400	2420	2500
F	COMPRESSOR PRESS: RATIO $\frac{\text{DELIVERY PRESS + BARO}}{\text{BARO − INTAKE DEP}}$	3·98	4·03	3·89	4·03	4·20	4·00	3·80	3·53	3·45	3·52	3·54
G	COMPRESSOR DELIVERY TEMP. DEG: F	325	328	328	325	330	340	332	335	336	340	352
H	AIR TEMP: to COMBUSTION CHAMBER (TA AVER) DEG C	287·2	290·5	286	286	285	292	297·7	302·7	302·7	301·6	299·5
J	H.P. TURBINE INLET TEMP: AVERAGE DEG: F	1165	1165	1165	1165	1165	1165	1165	1165	1165	1165	1165
K	H.P TURBINE INLET PRESSURE AVERAGE lb/sq" GAUGE	38·75	40	38·7	40·9	42·7	40·3	36·3	33·9	33·1	33·5	35·45
L	L.P. TURBINE INLET TEMP: DEG: F	847	868	863	875	870	880	876	883	890	890	881
M	L.P. TURBINE INLET PRESSURE. lb/sq" GAUGE	8·1	8·25	8·1	8·5	9·0	8·5	7·5	6·8	6·6	6·6	7·2
N	L.P. TURBINE OUTLET TEMP: DEG: F	690	703	700	700	691	709	720	732	739	738	722
P	L.P. TURBINE OUTLET PRESSURE. INCHES W.G.	5·4	5·8	5·4	5·8	6·0	5·5	4·7	4·3	4·1	4·1	4·6
Q	EXHAUST TEMP. DEG: F	496	506	507	511	508	526	515	520	535	532	533
R	OUTPUT K.W.	770	786	740	810	880	820	665	595	600	600	680
S	FUEL FLOW lb/HOUR (MEAN OF 12 READINGS)		763		853	884	810	686	663	650	667	689
T	SHIP'S SPEED. KNOTS	10·69	11·66	10·75	10·04	11·12	9·07	9·88	9·43	10·51	11·67	9·75
U	SLIP %	3·2	−4·8	4·4	8·3	1·4	5·3	3·3	2·1	0	−4·4	13·6
V	STATE OF EXHAUST SMOKE. H. M. L. C. *	V.C	V.L	L	L	L	L	C	L	L	M	L

CONDITIONS FOR A SET OF FIGURES.
(1) STEADY FOR 5 HOURS BEFORE FIRST OF 3 READINGS
(2) MEAN OF THREE CONSECUTIVE HOURLY READINGS

* H - HEAVY.
M - MODERATE.
L - LIGHT.
C - CLEAR.
V.C - VERY CLEAR

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was restarted as soon as the shaft speed had fallen to the normal figure.

The heavy heat exchanger and ducting are fixed at the bottom and are free to expand vertically by means of keys at the top, a method of support which proved very satisfactory under these most arduous conditions, while a thorough examination carried out later disclosed that no single part of the gas turbine installation had suffered in any way.

ROUTINE INSPECTION

Of the four rotating components of the set (alternator included) the h.p. turbine only was fully opened up for inspection during the two years' sea service. The condition of the air compressor blades was periodically observed by means of an introscope inserted through the clearance plug holes, while a portion of the l.p. turbine blades could be inspected through hand hole doors on the l.p. turbine exhaust.

The purpose of the compressor inspections was to ascertain the build-up of deposit on the blading and to observe the effectiveness of various methods of cleaning without opening-up. The method found most successful is described later.

The deposit found on the l.p. turbine blades is a light brown dust in a quantity too small to have any adverse effect upon performance, while so far as is known at present no corrosion or erosion has taken place. The conclusion reached regarding this component is that it will operate for an indefinite period without attention on all fuels with a viscosity up to 1,500 seconds. More viscous fuels have not yet been used on the *Auris*.

The h.p. turbine, which operates at the highest temperature and under the most severe conditions as regards impurities in the gases, formed the most important item for inspection. During the 24 months' sea service, the upper half of the casing was lifted three times and on two of these occasions the rotor was also lifted.

The first occasion was at Curaçao at the end of the first voyage after 618 hours full power operation, the total including shop trials being 1,297 hours. The set had operated in a most satisfactory manner during the voyage, the reason for opening up so early being to examine a welded part of the rotor shaft about which there was some apprehension. The weld in question dated from the time the set was built and the inspection proved the fears to be unfounded.

Prior to this inspection, marine Diesel fuel of 40 seconds Redwood I at 100 deg. F. viscosity was used. The fuel deposits on the first row of blades were not extensive, being about 10/1,000 inch thick, but were adhering firmly. The thickness of deposit on the subsequent rows became progressively less, there being no deposit on or after the fifth row. This component has seven rows of blades.

The rotor was not lifted on this occasion, so that the stator blades in the top half of the casing only were visible. On the front face of these, some patches of hard corrosion scale were adhering, some of which had cracked and fallen off, while the back face was fairly evenly covered by a dark grey substance, the composition of which is given in Table II. A few patches of fuel deposit on the front face were observed but at no point was the corrosion scale or fuel deposit of measurable thickness. What is referred to as "scale" is the product of oxidation of the steel, whilst "deposit" is from the products of combustion and is mostly composed of ash.

As already mentioned, patches of corrosion were observed on the first row stator and rotor blades and it was decided to order four rows of blading of superior material, the first and second rows to be made of Nimonic 80A and the third and fourth rows of FCBT steel. The composition and physical properties of the special steels used, namely R. ex 337A, and others to be used for the h.p. turbine blades are given in Table III.

The second inspection was carried out at Stockholm after

Table II.—Analysis of deposits

Date of sampling	Where sample was taken	Appearance	Ash per cent	Analysis of Ash per cent W: Vanadium as V_2O_5	Iron as Fe_2O_3	Sodium as Na_2O	Nickel as NiO	Chromium as Cr_2O_3	Calcium as CaO	Sulphate as SO_3	Undetermined trace elements	X-ray analysis
February 1951 (Rugby)	1st stage top half stator blades	Powdery dull yellow	97·8	42·0	6·6	10·9	9·1	—	7·3	17·9	—	
	4th stage top half 10 stator blades	Hard grey yellow flakes	94·5	75·0	1·3	7·3	5·5	—	4·1	11·4	—	Mostly $Na_2O.V_2O_4.5V_2O_5$
November 1951 (Curacao)	1st stage rotor blades	Dark grey flakes	99·4	5·1	47	3·0	12	13	—	—	Al, Ca, Cu, Mg, Tu, Co, Mo, Si	
	7th stage rotor blades	Red-brown powder	96·0	7·0	9·8	24	—	—	—	—	Ca, Al, Mg, Ni	
	2nd stage stator blades	Dark grey flakes	99·2	6·0	42	8·0	10	12	—	—	Al, Ca, Cu, Mg, Tu, Co, Mo	
	3rd stage stator blades	Red-brown powder	97·3	7·0	9·6	24	—	—	—	—	Ca, Al, Mg, Ni, Cr	
January 1952 (Stockholm)	1st stage top half stator blades	Dark brown powder	99·0	46	11	Not determined	9·0	—	—	—	Ca, Al, Mg, Cu, Pb, Na, Cr, Co, Mo	
	6th stage convex face top half stator blades	Brown powder	98	36	4·5	16	4·2	—	—	—	Ca, Al, Pb, Mg, Cr, Co	
March 1952 (Curacao)	1st stage convex face stator blades	Dark blue-grey powder, lumps and flakes		49	6·0	8·0	11	—	5·0	18	Cr, Mg, Al, Co	$Na_2O.V_2O_4.5V_2O_5$ and $CaSO_4$
	1st stage stator blade leading edge	One lump, partly red-brown, partly blue		53	2·0	5·0	5·0	—	12	20	Mg, Al	
	2nd stage convex face	Largely blue-grey, some red-brown powder and flakes		38	10	9·0	10	—	8·0	22	Cr, Mg, Al, Co	$Na_2O.V_2O_4.5V_2O_5$ and $CaSO_4$ + pattern F. (a compound so far unidentified)
	3rd stage convex face stator blade	Dark grey-blue powder and flakes		44	5·0	14	6·0	—	6·0	24	Mg, Al, Cr, Co, Mo	$Na_2O.V_2O_4.5V_2O_5$ and $CaSO_4$ and trace Na_2SO_4
	1st stage concave face stator blades	Dark blue- brown nodules and flakes		41	5·0	5·0	7·0	—	11	22	Al, Mg, Cr, Pb, Cu, Co, Sr	$Na_2O.V_2O_4.5V_2O_5$ and $CaSO_4$
	2nd stage concave face stator blades	Dark blue-brown flakes		54	4·0	5·0	6·0	—	12	19	Al, Mg, Cu, Co, Cr	$Na_2O.V_2O_4.5V_2O_5$ and $CaSO_4$
	3rd stage concave face stator blades	Dark blue-brown flakes		55	5·0	4·0	6·0	—	9·0	17	Mg, Al, Cr, Cu, Co, Sr	$Na_2O.V_2O_4.5V_2O_5$ and $CaSO_4$

TABLE III.—METALS USED FOR H.P. TURBINE BLADING

Material	Percentages of C	Si	Mn	Cr	Ni	Mo	Co	Cu	Tu	Others
R. ex 337A	0·2	0·8	0·8	17·5	17·5	3·75	7·0	3·0	0·8	
FCB (T)	0·12	0·6	1·2	18·0	12·0	—	—	—	—	Niobium 1·2
Nimonic 80A	0·1 max.	1·0 max.	1·0 max.	18 to 21	Balance	—	2·0 max.	—	—	Ti 1·8 to 2·7 Al 0·5 to 1·8 Fe 5·0 max.

a further 532 hours on load (total 1,829 hours), of which 135 hours were with the turbine burning high viscosity fuel of 1,338 seconds Redwood I at 100 deg. F. The rotor was lifted on this occasion.

The purpose of this inspection was two-fold. Firstly, to ascertain the blade condition as regards corrosion and obtain samples of scale and fuel deposits. In addition, confirmation was required that the scale and fuel deposits did crack and fall off the blades when the turbine cooled down at the end of a run, as indicated by the difference in the performance figures recorded just before the end of one run and just after the beginning of the next.

This inspection showed some further deterioration in the first two rows of stator and rotor blades and an increased quantity of deposit. Whilst the increased quantity of deposit was undoubtedly due to the use of heavier fuel, no definite opinion can be expressed as to whether the increased blade deterioration was due wholly or in part to the change of fuel. Also, it was noted for the first time that a portion of the blades represented by the 2/3 o'clock position of the first row of stator blades, when viewed from the exhaust end, were more affected than the blades in the remainder of the top half casing or any part of the lower half of the casing. Moreover, it was no longer possible to clean the blades to a smooth metal surface and the fuel deposits on the third row of blading were very hard and tenacious.

The second purpose of this inspection was to replace the studs connecting the two halves of the casing together, two of which had broken. After the initial test bed trial, it was found that the upper half of the casing had distorted slightly and that some of the studs had been unduly strained in endeavouring to bring the flanges together to form a gastight joint. After the two studs had broken, it was decided to replace all studs which had been excessively tightened. Since the over-strained studs were replaced and a certain sequence for tightening adopted, no further trouble has been experienced.

Most of the original studs had been secured by tack welding after fitting to prevent them unscrewing with the nuts, and their removal presented a difficulty on the ship where no special tools were available. Two studs had broken in service and two were found fractured when the top half casing was lifted, but owing to the toughness of the material they proved exceedingly difficult to drill and chip from the hole. Subsequent experience has shown that it is not necessary to secure these casing studs in the way described so long as they are well fitted. The suitability of the material used for these studs (R. ex 326F) is not in question because of the foregoing difficulties.

The high working temperature makes it difficult to remove nuts on the h.p. turbine and combustion equipment. The horizontal joint nuts are of the cap type and are made of stainless austenitic steel. The nuts and studs are fitted with a liberal coating of a cutting compound containing mica and this reduces the difficulty considerably. The cause appears to be binding between the nut face and the casing flange, for once a nut has been started it can be unscrewed easily. The application of heat expands the stud sufficiently to enable the nut to be started, and whilst a blowlamp has been used in the past it is hoped to use an ordinary kettle element placed round the nut in future.

The third inspection of the h.p. turbine was carried out at Curaçao after operating on fuel of 1,230 seconds viscosity for a period which included the voyage across the Atlantic when propulsion was by the gas turbine alone. The purpose of this inspection was to observe the effect of burning high viscosity fuel and to collect deposit and scale samples for analysis.

The photograph shown in Fig. 6 (Plate 1) is a view looking into the lower half casing from the high pressure end. Only a portion of the first row of blades is visible, the nearest row in full view being the second row. This photograph was taken after the turbine had operated on continuous load for 636 hours.

The quantity of deposit lying at the bottom of the casing may appear great, but it should be remembered that some is from the blades in the upper half of the casing and some from the rotor blades. The bulk of the deposit had cracked and fallen off during cooling but some can be seen loosely adhering to the second row of blades. The condition of the rotor blades was very similar to the stator blades shown in the photograph.

The progressive reduction in the quantity of deposit towards the low pressure end will be noted, the blades in the fifth row being almost free. A theory as to where this deposit goes if not manually removed will be given later.

The trailing edge of the first row of stator blades showed distinct signs of wastage. There was also a noticeable difference between the front and back faces of the top half stator blades. When viewed from the low pressure end, the first six blades, counting clockwise from the left-hand side, were completely free from deposit excepting for a soft local accumulation at the root of each blade. The surfaces of these six blades were rough and dark grey in colour.

On the blades to the right of the six referred to was a soft deposit which gradually became heavier as the right-hand side was approached. Underneath the deposit, which was easily removed, a hard white scale had formed, which could be removed but not easily. A feature noted on this occasion was that whilst the blades reported as most severely corroded at the second (Stockholm) inspection were coated with hard white scale, they now appeared better in this respect than those on the left-hand side.

During the voyage preceding the third inspection, temperature traverses were made of the ducts leading the gases from the two combustion chambers to the h.p. turbine. These disclosed that a variation of 200 deg. F. existed in each duct at a distance of 5·6 inches between the points of measurement. Also, it will be seen from the graph shown in Fig. 7 that, although the temperature generally was 1,180 deg. F., there existed an area where the temperature was 1,253 deg. F.

From this it is evident that the stratification which occurs due to imperfect mixing in the combustion chamber persists round the inlet bend and scroll; consequently, some stator blades will be subjected to higher temperatures than others. When the temperature exceeds 1,157 deg. F. (625 deg. C.), laboratory work indicates that corrosion proceeds at an accelated rate, probably due to certain constituents of the ash becoming molten. The exact point at which this occurs varies with the composition of the ash, but after 1,200 deg. F. (650 deg. C.) the corrosion rate is even more rapid.

It was also found in the earlier tests that when the lips on the shrouds became burnt, the temperature profile in the inlet ducts was affected, and this has subsequently been observed when any alterations or adjustments to the combustion equipment have been carried out.

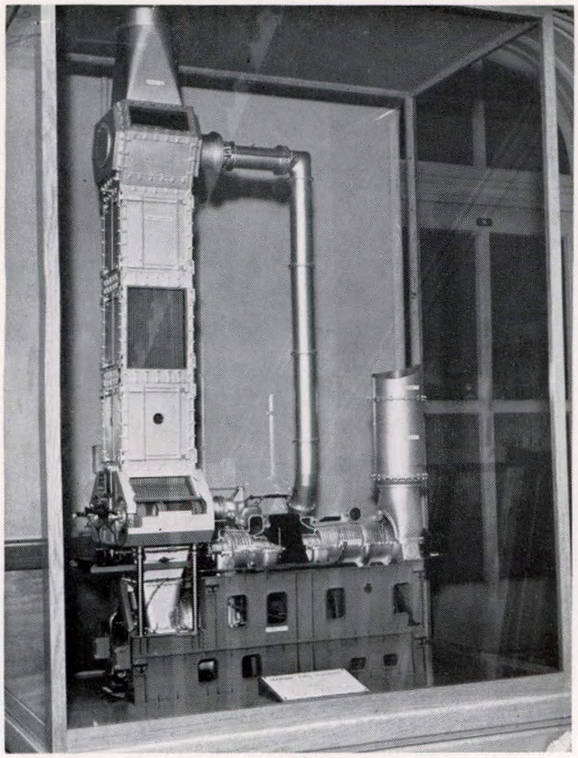


FIG. 2—*Sectional model of gas turbine set installed in* Auris

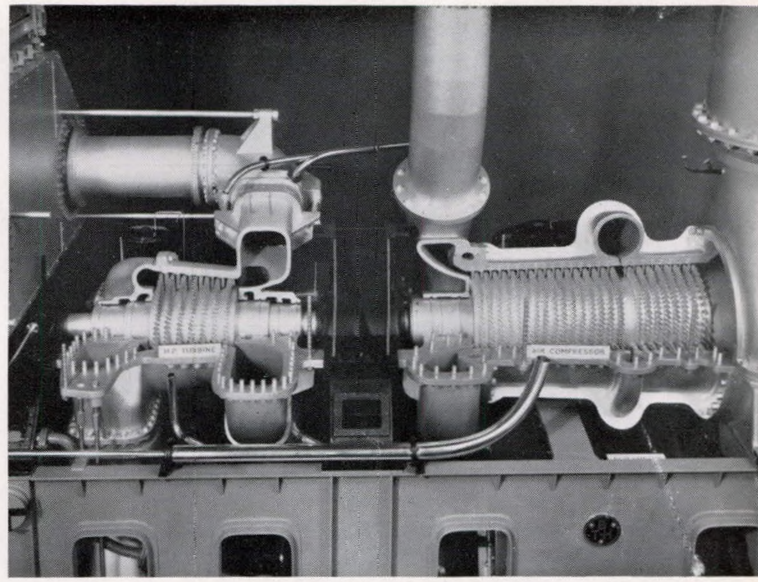


FIG. 3—*View of h.p. turbine and compressor in section taken from model shown in Fig. 2*

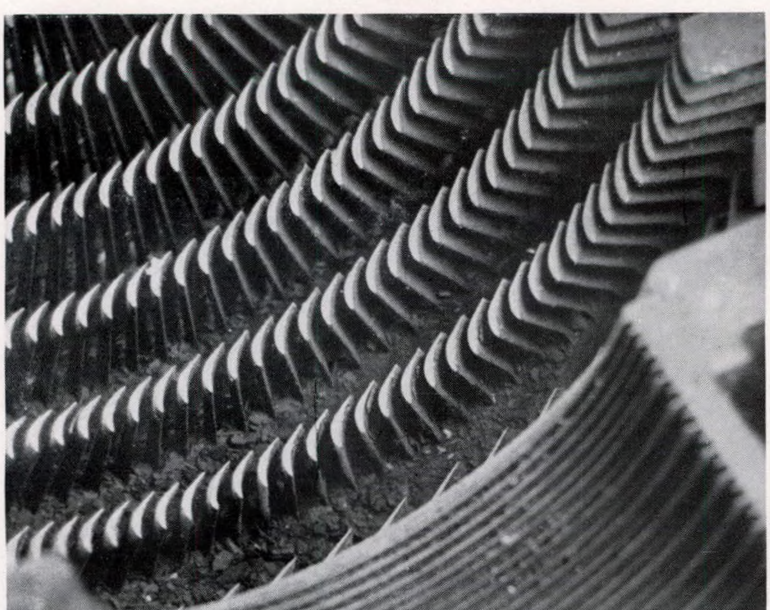


FIG. 6—*Photograph showing deposit at bottom of h.p. turbine casing after 636 hours on 1,230 seconds fuel*

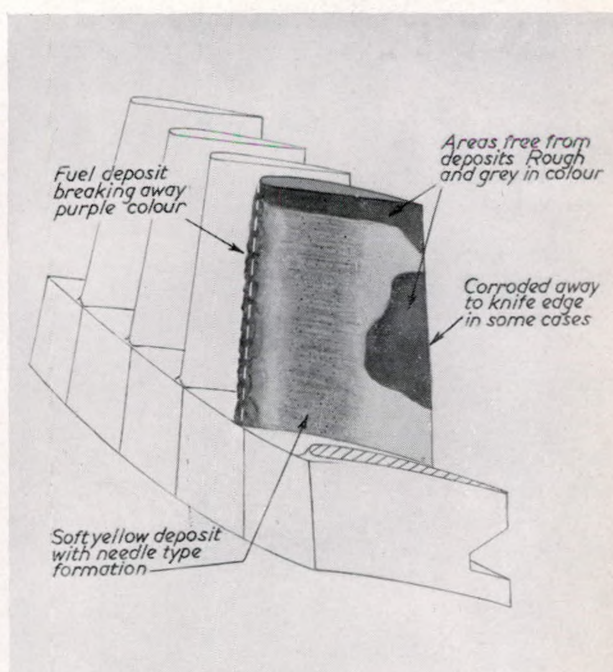


FIG. 8—*First row stator blade showing where corrosion takes place and fuel deposits accumulate*

Plate 2

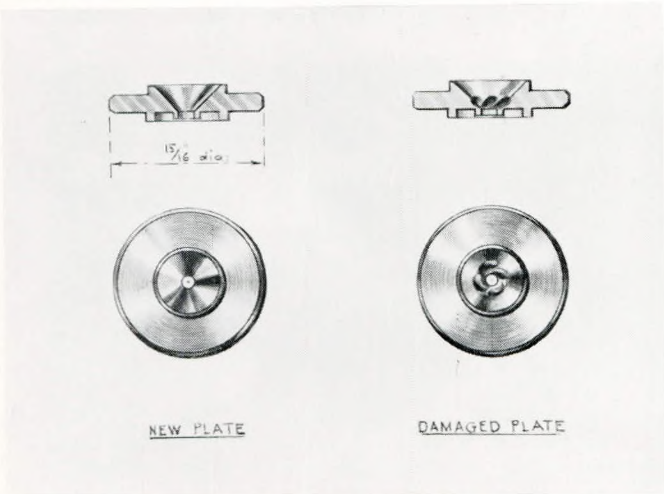


FIG. 12—*Damaged fuel burner orifice plate with new plate for comparison*

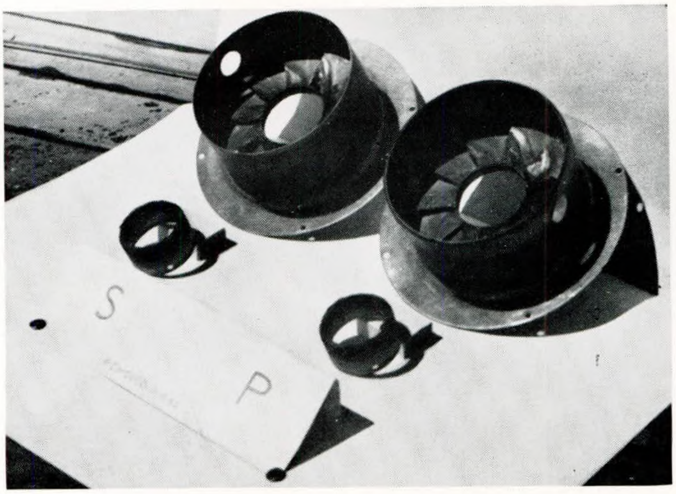


FIG. 13—*Badly burnt fuel burner shroud lips and swirler vanes, removed after 400 hours' operation*

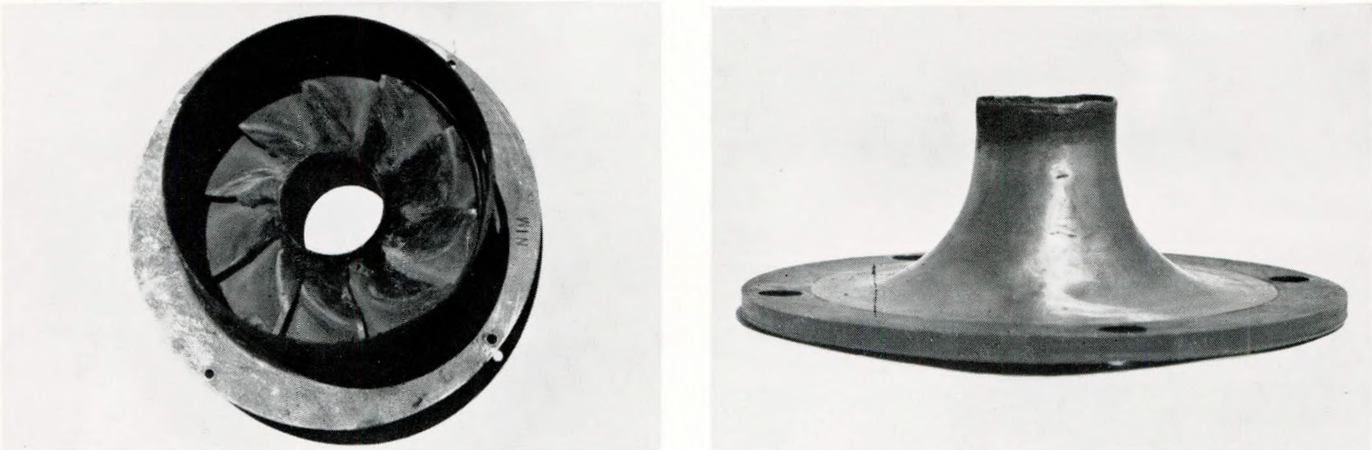


FIG. 14—*Modified design of combustion chamber components after 3,529 hours' running on marine Diesel fuel: (a) swirler vanes; (b) lipless shroud*

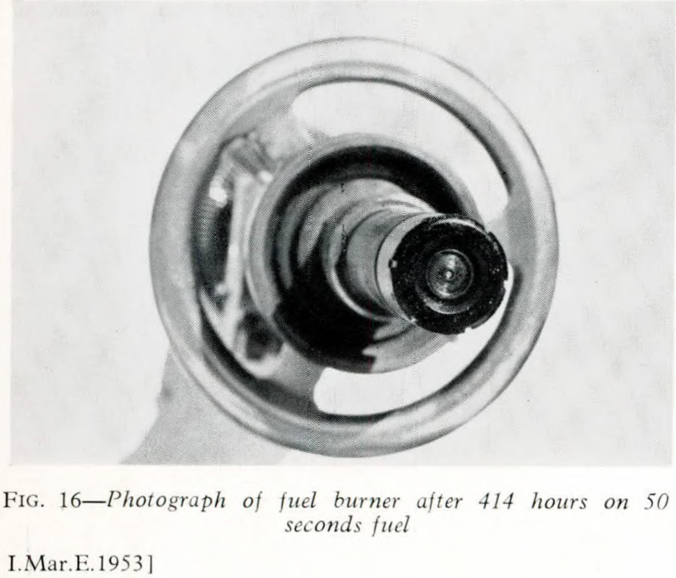


FIG. 16—*Photograph of fuel burner after 414 hours on 50 seconds fuel*

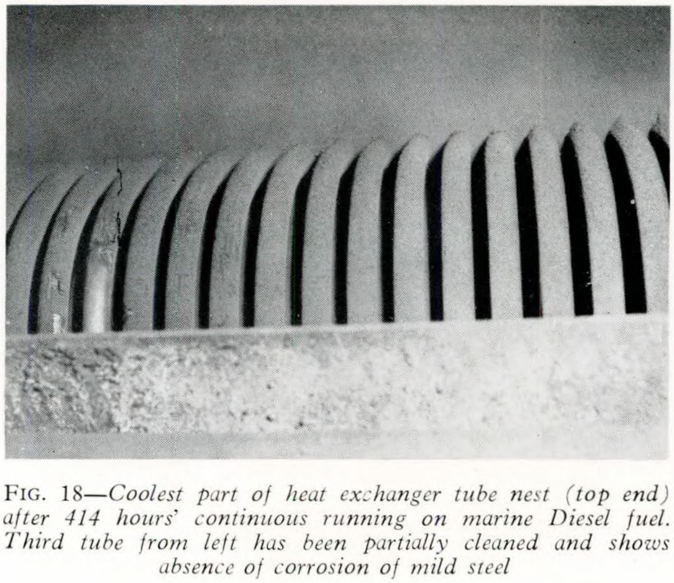


FIG. 18—*Coolest part of heat exchanger tube nest (top end) after 414 hours' continuous running on marine Diesel fuel. Third tube from left has been partially cleaned and shows absence of corrosion of mild steel*

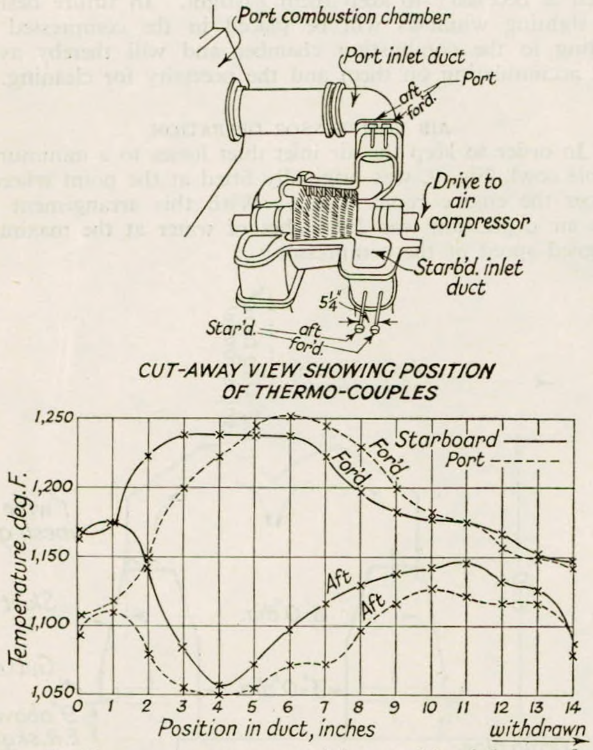


FIG. 7—*Temperature traverse of h.p. turbine inlet gas ducts*

Thus, the combustion changes carried out immediately before the second inspection can account for the most severely damaged areas of the first row stator blades moving from the 2/3 o'clock to the 10/11 o'clock position.

When opened up on this, the third occasion, a greater general accumulation of fuel deposits was found on the first few rows of blades, the measured thicknesses being as shown below:—

	Rotor (front face), inches	Stator (back face), inches
1st row	0·037	Unobtainable
2nd row	0·024	0·065
3rd row	0·012	0·034

The first row stator blades were almost free of deposit when exposed, it having evidently reached such a thickness and weight that it readily became detached and fell off during the thermal contraction of the blades at the end of the run. It was not possible to measure the thickness of the deposit but the assumption is that it was slightly in excess of that found adhering to the second row of stator blades.

An interesting feature is that the thickness of deposit on the second and third row stator blades is roughly three times that on the respective rotor blades. It does not follow from this, however, that the deposit on the first row stator blades reached treble the thickness of the corresponding rotor blades before it became detached, as these blades work at a higher temperature than those of the subsequent rows and thermal contraction upon cooling down would consequently be greater.

A sketch of one first row stator blade showing where corrosion had taken place and how the deposit was distributed over the surface is reproduced in Fig. 8 (Plate 1). Also, an analysis of the deposits is given in Table II.

A complete examination was again carried out on this occasion, the rotor lifted and all blading in this turbine cleaned. Some damage had been sustained by the horizontal joint where gas had blown across the face. This was due to insufficient tightening of nuts in very awkward regions and not to further distortion.

Inspections of non-rotating units have been more frequent. The doors of the heat exchanger, for instance, are opened at the conclusion of each long voyage and the tubes cleaned on each occasion, while the combustion equipment is inspected each time the set is shut down. The attention given to these parts is described later.

H.P. TURBINE OPERATION

The power output of the set is limited by a number of factors which operate under different conditions. The most important is the h.p. turbine inlet temperature, which is regulated by the fuel supplied to the burners. After the second inspection of the h.p. turbine, the maximum inlet temperature was, as already mentioned, restricted to 1,100 deg. F. in an endeavour to prolong the life of the turbine blades pending their replacement.

During normal running conditions at sea, only a small fluctuation of temperature occurs, but there are two factors in this particular set which have a major effect and may be worth mentioning. Firstly, as the turbine is not provided with a speed governor, the propeller shaft speed had to be regulated by varying the speed of the three Diesel engines. If the Diesel engine speed, and consequently the l.p. turbine speed through the alternator, is reduced, the gas inlet temperature rises due to the quantity of air flow being reduced. Secondly, a reduction of boiler steam pressure, and consequently temperature, reduces the turbine fuel temperature, the result of which is higher viscosity and a greater output from the burners. This in turn increases the inlet gas temperature. Both these undesirable effects can be overcome, the first by a suitable governor and the second by an automatic viscosity controller. As the ambient air temperature rises, the h.p. turbine speed increases for the same output. It is thus possible under certain air inlet conditions for the output of the set to be limited by the speed of the h.p. turbine; this never exceeds 6,000 r.p.m.

A further limitation occurs under tropical conditions when the h.p. turbine blading becomes dirty. The result of this is that the h.p. turbine outlet gas temperature rises, and when 900 deg. F. is reached, a maximum temperature determined by the heat-resisting properties of the l.p. turbine blade material, the fuel injected into the combustion chambers must be reduced.

The extent of corrosion of certain h.p. turbine blades has not yet been accurately measured as all original blades are still in use. When the most recent inspection was made corrosion was limited to the first four rows of stator and rotor blades. These blades, it might be pointed out, were made eight years ago of material which was the best then procurable. Since that time, superior material has become available and there is no doubt that considerably better results as regards resistance to corrosion will be obtained with the new blades.

A considerable amount of work has been carried out at Shell's Thornton Research Centre on the corrosion of alloy metals. From this it has been found that the rate of penetration of R. ex 337A, the material now in use, can be as high as 0·047 inch per 100 hours, whilst the penetration rate of Nimonic 80A, the material to be used in future, is 0·0069 inch per 100 hours. Both these results were obtained at a temperature of 800 deg. C., which, of course, exceeds the *Auris* maximum turbine inlet gas temperature of 650 deg. C.

A common feature of this corrosion is a rough grey surface near either the blade tip or trailing edge. The corrosion is attributed to certain constituents of the fuel ash formed on combustion. Two types of attack are recognized, one due to vanadium pentoxide (V_2O_5) and other vanadium containing compounds, and the second due to sodium sulphate (Na_2SO_4). The mechanism of the attack by vanadium bearing compounds appears to be one of accelerated oxidation, whereas that due to sodium sulphate is by intergranular penetration of the metal.

The severity of the attack is dependent on temperature and the onset occurs approximately at the melting point of the corrosive material. The melting points of V_2O_5 and Na_2SO_4 are 675 deg. C. and 880 deg. C. respectively and are, therefore, above the operating temperature of the *Auris* high pressure turbine, but in practice various other compounds and mixtures of compounds of vanadium and sodium occur, having lower melting points. Moreover, as mentioned earlier, it has been known for some time as a result of laboratory tests that alloys containing appreciable quantities of molybdenum, as does R. ex 337, have very low resistance to accelerated oxidation caused by certain constituents of ash in fuels.

There is no doubt that the h.p. turbine blades are the most vulnerable to attack, especially when burning normal grades of boiler fuels, but experiences ashore and afloat are encouraging. Rules for the periodical survey of gas turbines have not yet been formulated, but from all points of view it seems desirable, even at this early stage of the gas turbine development, that blade life should be not less than 20,000 hours, the equivalent to four years' service at 5,000 hours per year, and it is confidently expected that the materials chosen for the new blading in the *Auris* will fulfil this requirement.

It has been found that the thicker the build-up of fuel deposits the more easily it is removed. With the existing bla material, large quantities of deposit crack and fall off due to differential thermal contraction when the turbine is cooled down, and it is a reasonable assumption that starting up has a similar effect. It has been found that loss in efficiency due to deposit on the h.p. turbine is about 4 per cent after sixteen days' continuous running, and that this is regained by a shut-down of a duration sufficiently long to completely cool the turbine, i.e. twenty-four hours.

A large number of samples of deposits have been analysed and although it is not yet possible to correlate the nature of the deposit with any fuel characteristics, it is clear that there is some relation between the composition of the deposit and the temperature of the surface on which it formed. Chemical analyses show that, with decreasing temperature of the surface, the sodium to vanadium ratio always increases.

As will be seen from the photograph reproduced in Fig. 6 (Plate 1), a large proportion of the deposits formed on the blades crack and fall off whilst cooling down. The method adopted to remove that which does not shed is by individual manual scraping, an operation which takes two men twenty-four hours to clean the 1,100 stator and rotor blades.

It might be thought that, unless the loose deposits are removed from the bottom of the casing at frequent intervals, the free movement of the rotor would be affected. Contrary to expectations this does not happen, even though the rotor blade tip clearance is only 45/1,000 inch, which suggests that the deposits are quickly broken up into very small pieces, in which condition they are carried by the gas flow into the exhaust passage.

It will be recalled that upon starting, the bypass valve situated between the h.p. and l.p. turbines of the *Auris* set is opened to facilitate the operation, so that at this time the h.p. turbine exhausts direct to the heat exchanger. This no doubt offers an escape for the pulverized deposits discharged from the h.p. turbine each time it is started, and explains why the quantity does not go on accumulating in the h.p. turbine and why so little finds its way into the l.p. turbine. A surprising thing is that the deposits are broken up without damaging the blade tips in the least degree.

As already mentioned, some distortion of the h.p. turbine casing took place during the initial shop tests. This is confined to the top half, which has hogged a few thousandths of an inch. No further distortion has taken place. Four fitting studs act as dowels to counteract any movement between the two halves of the casing and to register them. During the period at sea no trouble has been experienced in this direction, proving that this method is adequate. Unfortunately no measurements can be made when the h.p. turbine is hot, but there has been little change in clearances when cold.

The combustion chamber sighting windows are cleaned each day; a variety of joints have been tried and soft asbestos has given the best results. If the joints are not replaced frequently, the glass becomes chipped due to excessive tightening, which is necessary to keep them gastight. In future designs the sighting windows will be placed in the compressed air ducting to the combustion chamber and will thereby avoid soot accumulating on them and the necessity for cleaning.

AIR COMPRESSOR OPERATION

In order to keep the air inlet duct losses to a minimum a simple cowl, Fig. 9, was originally fitted at the point where it pierces the engine room casing. With this arrangement the inlet air depression was 2·4 inches of water at the maximum designed speed of the compressor.

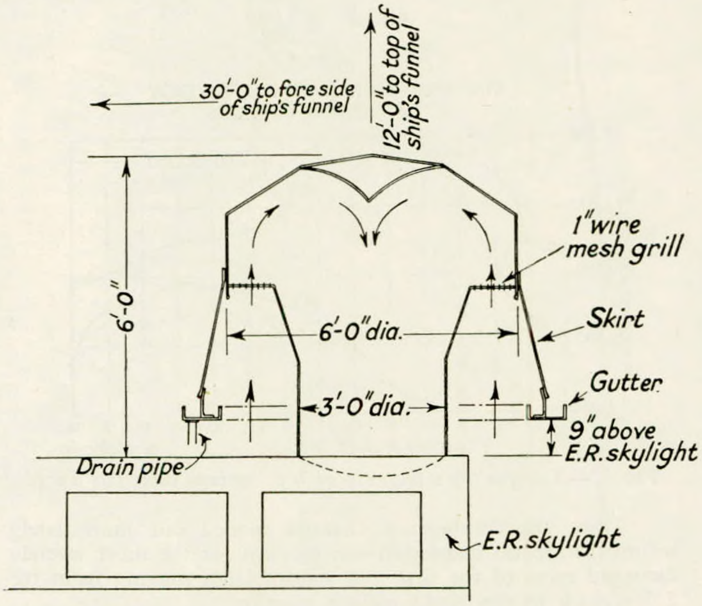


FIG. 9—*Air inlet to compressor showing skirt fitted to prevent entry of sea spray*

During the first voyage, exceptionally heavy weather was encountered and the cowl was often enveloped in sea water spray. On one occasion, during a tropical storm so much rain entered the suction that a stream of water issued from the drain at the inlet side of the compressor, which nevertheless continued to operate satisfactorily.

As a result of these experiences a skirt, gutter and drain were fitted to the cowl, as shown in Fig. 9. Since this alteration was made, the ship has encountered every kind of weather without experiencing trouble from this source, although with the suction in such an exposed position it is impossible to prevent some sea spray passing into the compressor. As some of the sea water solids adhere to the internal surfaces of the silencer and intake duct, four nozzles were provided as shown in Fig. 10. The practice is to connect these nozzles to one of the ship's fresh water pumps and wash the internal surface before cleaning the compressor.

In the 18,000-ton d.w. ship to be wholly propelled by gas turbines, the compressor will draw air from a rectangular shaped box situated in a position which will obviate entry of sea spray and gases from the funnel and the engine room skylights. The air inlet to the box is duplicated and arranged in such a way that there is a choice of inlets to suit the direction of the wind and sea.

Two kinds of deposit have been found in the compressor, one being from the salt laden air and the other lubricating oil vapour. The first appears as a white crystalline solid on the leading edge of the blades, and is easily removed by running the compressor at 400 r.p.m. by the starting motor and injecting in an upstream direction water, to which a proportion of the detergent Teepol has been added. This is followed by a fresh water wash by one of the ship's pumps until the drain

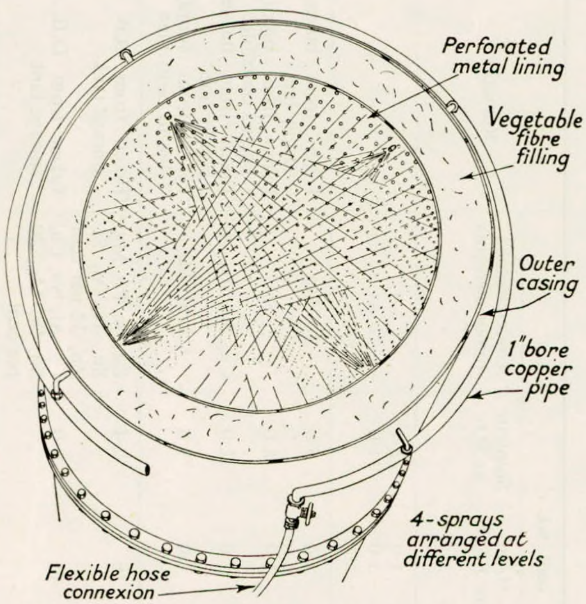


FIG. 10—*Fresh water spray for washing down air intake*

on the discharge end of the compressor emits clear water, the whole operation taking about twenty minutes.

The close proximity of the compressor air inlet to the skylight results in hot engine room air passing directly into the compressor when a following wind prevails. The compressor inlet temperature in such circumstances has on occasions risen suddenly by as much as 12 deg. F. The corresponding decrease in power output is about 130 b.h.p.

The air passing out of the engine room skylight generally contains a proportion of oil vapour from the crankcase of the three Diesel engines, particularly in hot climates. With the wind in certain directions, some is drawn into the compressor suction and adheres to the blades and casing surfaces as a black, sticky deposit. This assists other solids in the atmosphere to adhere and the compounded matter is much more difficult to remove. To remove this the procedure adopted is to slowly inject, preferably in atomized form, about 2 gallons of paraffin into the air stream when the compressor is turning at about 400 r.p.m. and follow this by Teepol and fresh water as already described.

The deposit resulting from operating the compressor in industrial areas is a black powdery variety which is readily removed. The basin trials of thirty-eight hours' duration after the turbine was installed at Hebburn-on-Tyne were sufficient to coat both the stator and rotor blades with a thin layer. This is perhaps understandable when it is mentioned that the air consumption of the *Auris* turbine is three-quarters of a ton a minute.

At sea the frequency of the cleaning operation depends mainly upon the state of the weather. For example, with the ship loaded in bad weather, the reduction in compressor efficiency during a voyage of sixteen days may be as high as 4 per cent, while on fine weather voyages of the same duration with the ship in ballast the reduction is not more than 1 per cent.

COMBUSTION EQUIPMENT OPERATION

When the gas turbine set was installed in the *Auris*, it had run on the test bed a total of 679 hours on fuels varying in

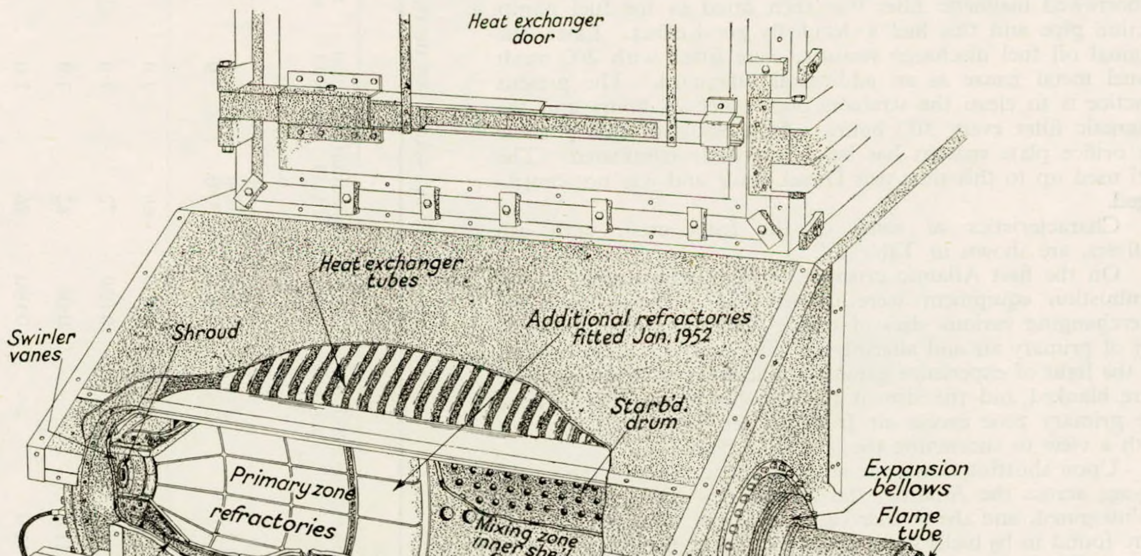


FIG. 11—*Internal arrangement of starboard combustion chamber*

viscosity from 40 to 1,500 seconds Redwood I at 100 deg. F. During this time a number of combustion changes were made in order to improve the flame shape and eliminate exhaust smoke.

These initial tests conclusively proved that the port mixing shell made of Nimonic 75 was superior to the starboard, which was made of Immaculate 5. At one time some damage was caused to both mixing zone shells due to four tongues of flame making contact with the metal. The tests, which had for their purpose the elimination of these tongues, had not been completed when the ship was ready to receive the gas turbine set.

In an endeavour to abolish the tongues of flame experienced during the shop trials, the four slots at the end of the primary zone were replaced by an annulus in order to redistribute the secondary air at this point, thus reducing local chilling of the combustion products, and also to protect the metal casing locally (see Fig. 11). Secondly, a new type of refractory containing 80 per cent alumina was used in two new primary zone shells, the used 70 per cent alumina refractories, complete with their shells, being kept on board as spares. The starboard mixing zone shell was at the same time replaced by a new one of Nimonic 75 material.

These modifications greatly improved the shape of the flame at light loads, but tests had at this stage to be suspended because the fuel burner orifice plates began to wear rapidly due to fine grit and pieces of corrosion scale in the fuel. The usual precautions had been taken to clean out the fuel system but it soon became apparent that, when such a power unit is installed in a ship, exceptional care must be taken to ensure that the fuel system is scrupulously clean.

Because of the grit, the first pair of damaged orifice plates had to be replaced after operating for only thirty-eight hours. Fig. 12 (Plate 2) illustrates where the erosion took place. A borrowed magnetic filter was then fitted in the fuel pump suction pipe and this had a decidedly good effect. Later, the original oil fuel discharge strainers were fitted with 200 mesh monel metal gauze as an additional safeguard. The present practice is to clean the strainers once every 24 hours and the magnetic filter every 500 hours. As a result of this practice the orifice plate erosion has been practically eliminated. The fuel used up to this time was Diesel grade and was not centrifuged.

Characteristics of some of the fuels used, with ash analyses, are shown in Table IV.

On the first Atlantic crossing, various adjustments to the combustion equipment were carried out. These comprised interchanging various sizes of orifice plates, varying the quantity of primary air and altering the axial position of the burner. In the light of experience gained, six holes in each mixing shell were blanked and the size of the annulus reduced to increase the primary zone excess air from 66 per cent to 92 per cent with a view to shortening the length of flame.

Upon shutting down the set at the conclusion of the return voyage across the Atlantic, the shroud lips (Fig. 13, Plate 2) disintegrated, and the swirler vanes, made of Nimonic 75 steel, were found to be badly burnt, necessitating replacement of both parts. Previously these parts had been made of F.D.P. steel, which was inferior to the Nimonic 75. Experience up to this stage of the experiments indicated that, with the existing design of combustion equipment, the replacement of these small parts at intervals of about 400 hours would have to be accepted for the time being. In an endeavour to reduce the cost of replacements, the shroud design was modified so that the ends with lips only required to be replaced. Subsequently, a similar modification was made whereby the vanes only of the swirlers required to be replaced in the existing draught tubes.

Before beginning to burn normal grades of boiler fuels, a further ring of 80 per cent alumina refractory bricks was added to each combustion chamber (see Fig. 11), the purpose being to prolong the life of the mixing zone shells at the possible expense of slight additional pressure drop.

The burning of this grade of fuel did not present any difficulty so long as the fuel was double centrifuged and the

TABLE IV.—ANALYSIS OF FUELS USED

Date of sampling	Fuel characteristics: Specific gravity at 60/60 deg. F.	Viscosity (Red. I at 100deg. F.), sec.	Carbon residue, per cent wt.	Sulphur, per cent wt.	Ash, per cent wt.	Ash analysis per cent wt.: Vanadium as V_2O_5	Nickel as NiO	Sodium as Na_2O	Calcium as CaO	Iron as Fe_2O_3	Sulphate as SO_3	Undetermined minor elements	Remarks
January and February 1951	0·98 0·957	989 1,440	8·6 9·9	2·5 2·15	0·062 0·069	72·0 70·0	7·4 7·0	5·0 8·3	2·5 2·4	1·6 1·0	8·1 11·0	— —	
March 1952	0·962	1,230	10·2	2·63	0·050	66	7·0	7·0	6·0	1·0	9·0	Sn, Mg	Taken from burner supply line
March 1952	0·961	1,220	—	—	0·050	72	7·0	3·0	5·0	1·0	8·0	Si	Taken from supply line to centrifuge
May 1952	0·963	1,440	11·2	—	0·08	82	7·0	2·0	—	1·0	12·0	Ca, Si, Mg, Al	Taken from burner supply line
May 1952	0·964	1,470	11·0	—	0·090	76	7·0	7·0	—	1·0	7·0	Ca, Si, Mg	Taken from supply line to centrifuge
July 1952	0·8595	42	1·67	1·06	0·058	22	1·0	5·0	—	16	2·4	Ca, Ba, Pb, Mg, Sn, Ti, Al, Si, Zn, 32 per cent	Taken from D.B. storage tank
July 1952	0·8820	53	4·15	1·38	0·047	56	4·0	—	—	11	9·0	Ca, Al, Na, Cu, Sn, Si, Mg, 20 per cent	Taken from D.B. storage tank

swirler vanes and shroud lips remained intact. These small parts, however, deteriorated rather more rapidly with this grade of fuel and consequently the exhaust gases became discoloured, which in turn caused a greater accumulation of fuel deposit in the heat exchanger.

On one occasion, when the entire shroud lip was found to have burnt away, the flame length was seen to be unusually short. As such a length was desirable, two shrouds without lips were tried. These gave the desired results as regards length of flame, but did not prove altogether satisfactory as the flame became unsteady. The results, however, warranted further experiments with this type of shroud, but of a reduced diameter. This, of course, necessitated a modified design of swirler vane.

The success of this new design was immediately apparent and the first set gave 3,529 hours' service before being replaced. Fig. 14 (Plate 2) shows the parts after removal. With this design the exhaust gases were colourless and the flame bright, short and clear of the mixing zone shell. The tongues of flame which had hitherto persisted at medium and full loads were now eliminated. The only disadvantage resulting from this alteration is that the burners must be moved axially when changing from light load to full load running, in order to prevent the flame striking the primary zone wall and causing a carbon build-up on the refractories.

While the set was undergoing shop trials at Rugby, the possibility of the refractories disintegrating and causing damage to the h.p. turbine blading was recognized. It was not considered practicable to fit a protective grid in the inlet ducts, as it might cause an undesirable pressure drop. The h.p. turbine blades were not, therefore, protected in any way against pieces of refractory that might break away, but both combustion chambers were carefully examined at every opportunity and a full record made of each crack and missing piece until the most suitable refractory material had been found. The bricks fitted for the basin trials are still in use. Fine cracks have formed and small pieces have broken from the edges and corners of the bricks but no damage to the blades has resulted from this cause.

Experience has shown that the gas velocity is not sufficient to carry into the turbine pieces of refractory large enough to cause damage. Any pieces which do break away are mostly found on the bottom of the primary zone shell. This would suggest that if the combustion chambers are disposed vertically, the fuel and air entering at the lower end, no anxiety need be felt regarding slight disintegration of the refractory, though ultimately, no doubt, a material which is completely satisfactory will be found.

The refractory bricks originally fitted in the *Auris* combustion chambers were secured in the primary shell by lugs welded on the downstream end. This prevented the replacement of individual bricks on board and the design has now been modified to enable the conical portion of the shell to be separated from the barrel portion (see Fig. 11). Should it become necessary, it is now possible for the ship's staff to renew part or the whole of the combustion chamber lining, an operation which will be much easier when dimensions of bricks can be guaranteed to closer tolerances. It was also found that to preserve the locating lugs, which tended to burn away, gripping of the bricks, which allowed direct conduction, must be avoided. In addition, air cooling holes were drilled close to the welds, since when no further trouble has been experienced.

The improvements in the combustion equipment which have resulted in a shorter flame, and the use of Nimonic 75 material for shrouds, swirler vanes and mixing zone shells, have greatly increased the life of the latter. With high viscosity fuel, some scaling and corrosion takes place but the life of the existing shells is expected to exceed 25,000 hours.

Fig. 15 shows a sectional view of one of the six original fuel burners supplied to the ship, two working and four spares, and which are still in use. These have often run for hundreds of hours without attention, particularly since the fuel system was completely cleared of grit. A photograph of one such burner after 414 hours is shown in Fig. 16 (Plate 2).

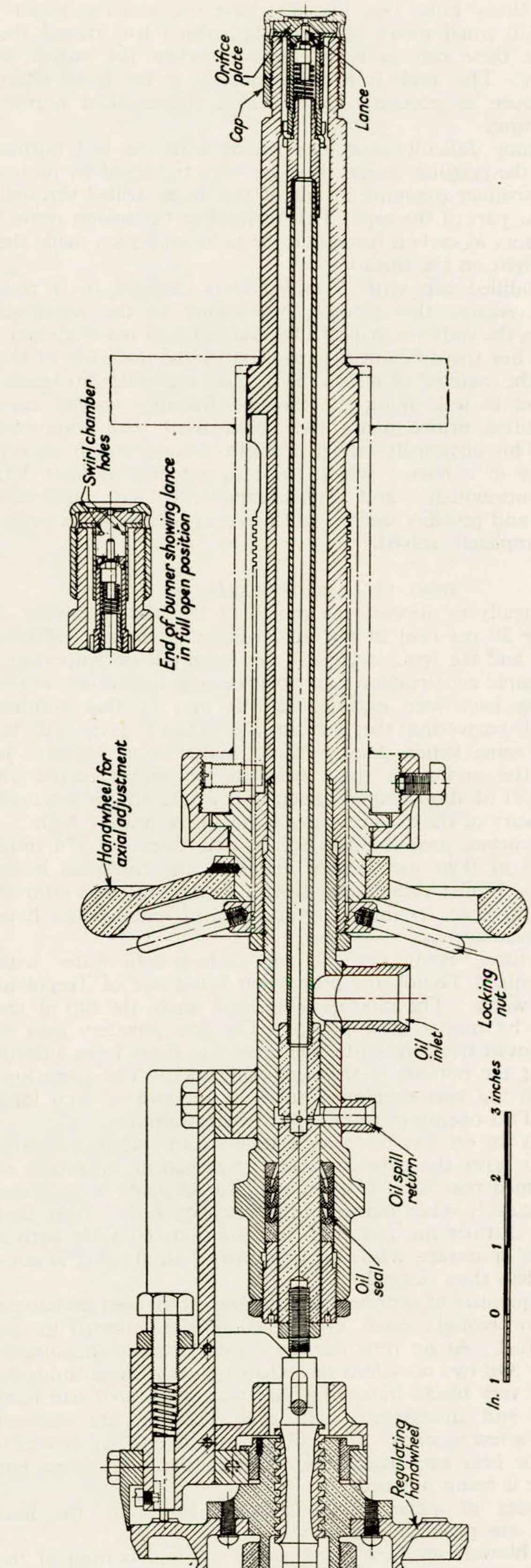


FIG. 15—*Sectional view of fuel burner*

Apart from the orifice plate erosion mentioned earlier, some of the swirl sleeve holes (see Fig. 15) have on occasion become choked with small pieces of scale, etc., which had passed the filters, but these can easily be removed when the burner is withdrawn. This fault is readily detected, as the usual effect is to produce an eccentric flame and a higher than normal burner setting.

A minor difficulty was experienced with the fuel burner caps. In the original design the caps were tightened by means of a "C" spanner engaging in one of two holes drilled through the circular part of the cap. This method of tightening proved unsatisfactory as carbon formed in the holes and often made the cap very tight on the thread.

A modified cap with 6 milled slots engaged by a ring spanner overcame this trouble, but owing to the restricted dimensions the ends sheared off. Several different materials were then tried but the differential expansion of the materials of the caps and the material of which the burners was made invariably caused fuel to leak along the thread. Recently shorter caps with modified orifice plates have been tried with improved results. This outwardly trivial problem assumes much greater importance in a burner which must operate for at least 500 hours continuously, and more experience with different materials, and possibly design, will be required before the problem is completely solved.

HEAT EXCHANGER OPERATION

As already mentioned, the weight of the heat exchanger is 16 tons or 29 per cent of the total weight of the set. Whilst its weight and the space occupied may seem out of proportion, it is of simple construction and no operating difficulties worth mentioning have been experienced. It may be that another method of recovering the heat in the exhaust gases will be found at some future time but, no matter what method is adopted, the saving in space will not be great because an exhaust duct of almost equal dimensions would still be required if the velocity of the exhaust gases is not to be unduly high.

The surface area is 3,500 sq. ft. and there are 576 mild steel tubes of 0·90 inch inside diameter, the thickness being 0·08 inch. Whilst this design gives a modest thermal ratio of about 52 per cent, its simplicity and ease of maintenance have proved advantageous.

The tubes, being vertical, are washed with water with which is mixed Teepol, the proportion being one of Teepol to twelve of water. The mixture is sprayed on to the top of the tube nest by means of a pump. The fine powdery soot is easily removed from the entire tube nest and flows from a drain situated at the bottom of the heat exchanger. The procedure is to wash the heat exchanger tubes at the end of each long voyage. This operation takes about twenty minutes.

When the set was being shop tested, soot was occasionally blown out with the exhaust gases. Subsequent operation at sea confirmed that there is a tendency for deposits to accumulate, particularly when burning high viscosity fuels. Also, that there is a distinct fire risk if these conditions coincide with a shut-down or restart, when the quantity of air flowing is considerably less than normal.

The quantity of deposit accumulating on the heat exchanger tubes is surprisingly small, even when burning normal grades of boiler fuel. At no time has the deposit reached measurable thickness. On two occasions the exhaust gases became suddenly dense and very black, indicating that pockets of soot had been dislodged and discharged. On each occasion the exhaust cleared in a few seconds. It is still not possible to say at which part of the heat exchanger this accumulation takes place but the matter is being pursued.

Analyses of some of the deposits found in the heat exchanger are given in Table V.

Soot blowers are now fitted at the top and bottom of the heat exchanger. These will operate on steam from the auxiliary boiler and are of the multiple rotating nozzle type. The alternative medium of compressed air was considered but steam has an advantage in that it can be used to extinguish fires should

TABLE V.—ANALYSIS OF HEAT EXCHANGER DEPOSITS

Date of sampling	Appearance of powder	Ash, per cent wt.	Analysis of ash per cent weight						Remarks
			Vanadium as V_2O_5	Iron as Fe_2O_3	Nickel as NiO	Sodium as Na_2O	Aluminium as Al_2O_3	Undetermined minor elements	
February 1951 (Rugby)	Black powdery	9·6	53·8	8·4	6·4	10·9			Sample taken from bottom (hot end) of tubes after 336 hours on 1,500 sec. fuel. Weight of deposit per foot of tube = 0.87 gm.
	Black powdery	10·2	40·0	27·1	4·7	7·5	3·0		Sample taken from middle of tubes after 336 hours on 1,500 sec. fuel. Weight of deposit per foot of tube = 0·91 gm.
	Black powdery	9·3	53·0	13·5	6·4	9·5	0·5		Sample taken from top (cold end) of tubes after 336 hours on 1,500 sec. fuel. Weight of deposit per foot of tube = 1·875 gm.
November 1951 (Curacao)	Soft black powder	7·4	14	31	—	—	—	Na, Ca, Al, Ni, Mg (Remainder)	Sample taken after 618 hours when burning marine Diesel of 40 seconds (Red. I at 100 deg. F.) viscosity
	Soft black powder	6·3	17	14	—	—	—	Na, Ca, Al, Ni, Mg (Remainder)	Sample taken after 618 hours when burning marine Diesel of 40 seconds (Red. I at 100 deg. F.) viscosity

they occur. The available steam pressure is 120lb. per sq. in. and the quantity of steam relative to the gas flow is small, but it is anticipated that it will be sufficient to set up local eddies in the gas stream and assist in dislodging the accumulated pockets of deposits.

Towards the end of the first year's operation it was thought from instrument readings that some of the heat exchanger tubes were leaking. The readings indicated a sudden increase in the estimated equivalent area and one possible explanation was leaks in the tubes. A test was made pressurizing each tube separately by means of the apparatus shown in Fig. 17 and an air leak was found in one tube which had split axially. The conclusion reached was that the cause was faulty material. The defective tube was plugged at both ends and no further trouble with tubes leaking has been encountered. The tubes, which are made of mild steel, were found quite free from corrosion and the indications are that, apart from periodical washing, they will not require attention for a very long time (Fig. 18, Plate 2).

USE OF WASTE HEAT

With an exhaust temperature at the heat exchanger outlet of 500 to 550 deg. F., it would evidently have been possible to use some of the heat in the exhaust gases to raise steam in a boiler, but in the *Auris* the space restrictions already mentioned would have made the inclusion of a waste heat boiler above the heat exchanger impracticable.

In general, however, the fitting of a waste heat boiler will be profitable since even with turbines of greater thermal efficiency having an exhaust gas temperature of 430 deg. F., it will be possible to raise 700lb. of steam per hour at 125lb. per sq. in. for every 1,000 b.h.p. of main propulsive power; if a steam pressure of 50lb. per sq. in. can be accepted, the figures will be 1,000lb. per hour per 1,000 b.h.p.

Owing to the small temperature difference between the gas and the steam, the boiler surface required will be relatively large, and it must be disposed so as to have as small a draught loss as reasonably possible since every 1 inch W.G. increase in the back pressure will cause a loss in the main turbine output of the order of ½ per cent.

INDICATING INSTRUMENTS

The instrumentation of a marine gas turbine is of the utmost importance, particularly if, as in the case of the *Auris*, the installation is experimental. This presented a number of new problems.

The instruments, for instance, must be sufficiently accurate and reliable to enable the efficiencies of the various components and loss of area due to the presence of deposits to be calculated. In the *Auris*, the temperatures to be measured vary from 0 deg. F. to 1,200 deg. F., and the instruments must of necessity be inserted in variable cross section ducts, subject to high velocity gases and vibration produced by the Diesel engines, reciprocating pumps and propeller, as well as corrosion products.

The power output is controlled by the gas inlet temperature to the h.p. turbine. This is measured by thermocouples in conjunction with a robust galvanometer type instrument on a special resilient type mounting. Initially, one thermocouple was placed in each port and starboard duct but they were clearly reading inaccurately and varied with each combustion change. A temperature traverse of each duct was made along two parallel lines 5¼ inches apart and both in the same plane transverse to the gas stream; the results showed a very uneven profile. Fig. 7 shows the result obtained at a nominal temperature of 1,180 deg. F. By redesigning the combustion chamber, it is considered that a much more uniform temperature profile could be obtained, but this would take a long time. For operation of the turbine a more immediate solution was to fit more thermocouples, and in this way the instrument gives a reading closer to the average temperature at various loads.

During the first year of operation the original thermocouples had to be replaced due to the effect of high temperature,

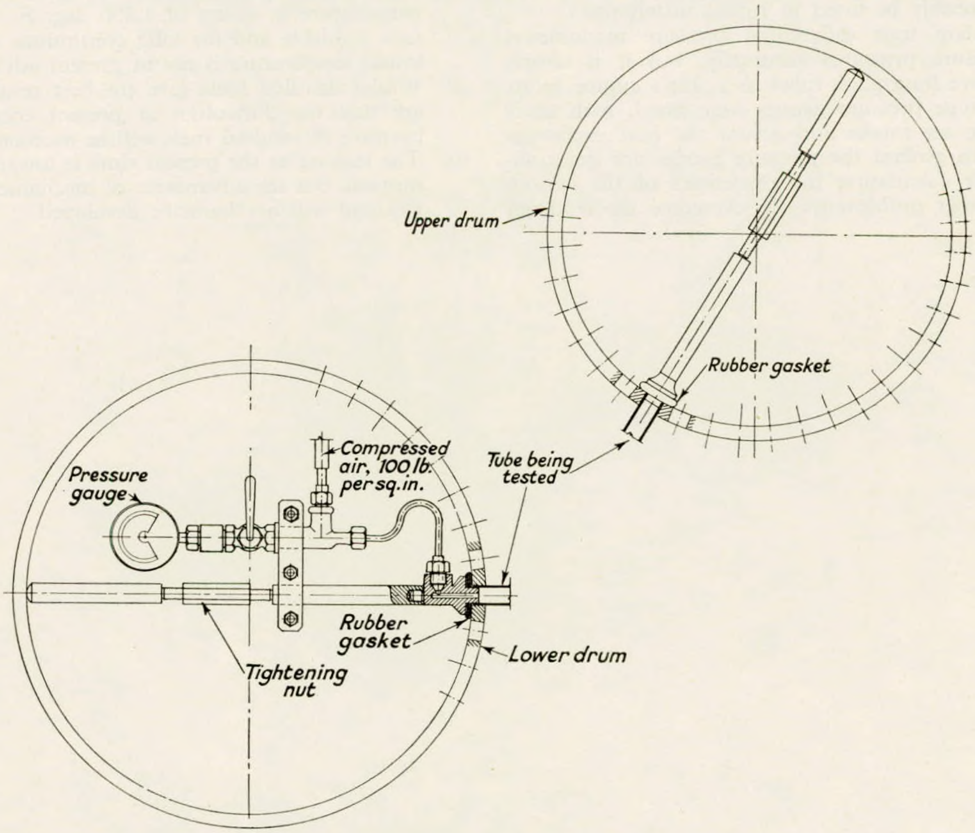


FIG. 17—*Device for pressure testing heat exchanger tubes*

and the compensated leads perished at the places where they passed close to the h.p. turbine. The instrument itself had to have new pivots, after which it was mounted on another part of the ship's structure with improved results. It was clear that the actual figure obtained from this instrument could not be used for calculating purposes, but it does enable the ship's engineers to operate the turbine without having to calculate the inlet temperature from the h.p. turbine outlet temperature and the temperature rise of the air passing through the compressor.

Most of the other temperature instruments are of the mercury in steel distant reading type and, therefore, suffer a 1 or 2 per cent discrepancy and are liable to be damaged by vibration. Where possible, mercury in glass thermometers have been used, but the rate of destruction is high and it is difficult to place them in a large diameter duct at a point where the temperature reading is required.

The thermometer inserted in the 30in. diameter air inlet duct had a particular problem. The chemical solutions used for cleaning the compressor, as well as the salt laden atmosphere, caused heavy corrosion and it was feared that pieces would break off and damage the compressor blading. It was necessary, therefore, to inspect these thermometers frequently and to remove them at the first sign of corrosion.

The designed method of reading each turbine speed is by means of a tachogenerator mounted on one end of each turbine shaft and coupled electrically to a voltmeter type tachometer. This method of registering the speed proved very inaccurate due to errors in each voltmeter and an alternative means has had to be introduced. A Maxwell electronic type instrument was used but, whilst it registered correctly, it is not suitable for general marine use. More recently an electronic counter has been tried, but again, whilst it gives the accuracy required it is doubtful if it will be suitable for general marine gas turbine operation. Attempts to find a robust tachometer accurate to within 0·1 per cent, either electrical or mechanical, have so far been unsuccessful, but a tachogenerator synchronized to a counter instrument will probably be fitted to future installations.

During the shop tests differential pressure manometers were used to measure pressures accurately, but it is clearly impracticable to have long glass tubes in a ship's engine room. Normal Bourdon type pressure gauges were fitted, with small manometers on the air intake and across the heat exchanger on the gas side. In general the pressure gauges are not sufficiently accurate for calculating the efficiencies of the various components. Another problem was to overcome the tendency of the h.p. turbine pressure points and piping of gauges to choke. A system of blowing these pipes through with compressed air has been devised but improved results will be obtained by providing pipes of larger bore. In addition to the instruments mentioned above, a number of special instruments for specific tests have been required. These would not normally be used by the ship's engineers.

CONCLUSION

After two years' sea experience with the first gas turbine propelling set to be installed in a merchant ship, the authors' views are as follows:—

1. There is nothing in its operation which is beyond the capacity of the average ship's engineer. The absence of noise and vibration are considered to be desirable features.
2. The gas turbine is not affected mechanically by any conditions likely to be encountered at sea in any part of the world.
3. There is no reason why future gas turbine installations should not operate efficiently and continuously on the longest voyages.
4. Apart from defects in materials and workmanship, the life of the major parts (h.p. turbine blades excepted) of a conservatively rated installation will not be less than the life of the ship.
5. A life of not less than 10,000 hours may be confidently expected from h.p. turbine blades if made of the best material now procurable.
6. Whilst for equal power output the gas turbine has the advantage in weight and space occupied, and will in the not far distant future compare favourably with the Diesel engine in the matter of fuel economy, its main advantage is likely to be low maintenance cost.
7. In contemplated gas turbine installations the emphasis should be on simplicity of construction until more experience has been obtained under arduous sea conditions.
8. Satisfactory operation may be obtained with a gas inlet temperature in excess of 1,200 deg. F., but with materials now available and for long continuous operation, a higher initial temperature is not at present advisable.
9. Whilst distilled fuels give the best results, the indications are that the difficulties at present encountered with the burning of residual fuels will be overcome.
10. The leaning at the present time is towards electrical transmission, but the advantages of mechanical drive are attractive and will no doubt be developed.

Discussion

SIR HAROLD ROXBEE COX, in opening the discussion, said that it would be generally accepted that for many years past Great Britain had been the leading maritime nation. He did not know to whom the credit for that could be given—probably Alfred the Great. For some years past, too, Great Britain had been the leading gas turbine nation. He had no doubt at all to whom the credit should be given for that—to Frank Whittle. If the two things could be taken together, Great Britain was now in a fair way to being the leading maritime gas turbine nation; and while Her Majesty's Navy had done a great deal towards putting Great Britain in that proud position, there was no single name to which greater credit for that state of affairs could be allotted than that of Mr. John Lamb. Mr. Lamb had no doubt had a great deal of help from his colleagues—Whittle had a great deal of help from his colleagues, and no doubt Alfred the Great had a great deal of help from his colleagues—he could not for the moment recall their names—but Mr. Lamb had been the pioneer in what was undoubtedly a classic experiment. The greatest credit reflected not only upon Mr. Lamb but also on his company and his colleagues. Mr. Lamb obviously had an unusually enlightened board of directors.

The great feat which had been the subject of the paper, however, could not have been possible without first class engineering of the engine itself, and he wished to mention Mr. Forsling, the designer of the engine, and the great British Thomson-Houston Company, the engineers of it. Therefore, there was a great team of people who had reason to be proud about the achievement which was the subject of the paper.

He felt that, from the marine point of view, it was perfectly proper to think of the *Auris* at the same time as one thought of the *Turbinia*. He had not the slightest doubt that the experiment would have the greatest influence on the future of the mercantile marine. It would be foolish for him, who was known to some of those present, to deny a certain enthusiasm for the gas turbine, but, like Mr. Lamb, he had a certain weakness for the Diesel engine as well, which he thought would be with them for a very long time and had many years of valuable service ahead. At the present time the efficiency of the Diesel engine in ships was about twice that of the gas turbine, and in that respect the gas turbine had a long way to go. In other respects, perhaps, it could already show an advantage. Mr. Lamb had pointed out the great advantages from the maintenance and weight point of view, but there was another weight which he was sure all marine engineers would bear in mind—it must surely be as important to them as it was to the aircraft engineer—and that was the weight of the power plant plus the weight of the fuel it needed to do the job it had to do, and in that respect he did not think the gas turbine was at present in the lead. But for smooth running the gas turbine had a great deal in its favour. It had another thing in its favour and that was the extraordinarily wide range of fuels that it could burn, and in that he thought it would see the Diesel engine off. At the present time, as well as burning the fuels which Mr. Lamb and Mr. Duggan had mentioned in their paper, the gas turbine was burning coal and also peat. Neither of those fuels was likely to be at all attractive to Mr. Lamb but, nevertheless, that was indicative of the extraordinary omnivorousness of the gas turbine and it was a feature of the engine which would make it extremely attractive for a number of applications.

In his preamble, Mr. Lamb had mentioned the gas turbine later developing an efficiency of 45 per cent. He was pleased that Mr. Lamb had done so, and he felt in agreement with him, but he considered that there was a great deal to be done before an efficiency of that order was attained. He thought that it was possible, but there were very great hurdles to be overcome before it was achieved. For one thing, they had to have high temperature operation at temperatures probably twice those at which they were at present operating in the *Auris*; also it must be remembered that the *Auris* gas turbine, admirable as it was, had been operating at a relatively low inlet temperature, a temperature at which, though there had been deposits to be got rid of, attack from vanadium pentoxide, or whatever form vanadium took when it was at its most insidious, was not very potent; but as the temperature was stepped up, that attack would become more and more dangerous. At the present time, because of the vanadium trouble, he felt that the problem of burning residual oil was even more difficult than the problem of burning coal and peat. That was not to say that it was a problem of which they should be frightened in any way. He thought it would be overcome, but it was one of those things which had to be overcome before very high efficiencies were attained.

It was interesting to realize that the solution might be, so to speak, an aerodynamic one rather than a metallurgical or a combustion one. If they were clever in the way they cooled the turbine blades, the method that kept them down to a temperature which was not difficult from the point of view of attack from vanadium might also be arranged to blow away the deposits which tended to stick to the blades and cause them to deteriorate. Many of those present would know that he was referring to systems of cooling which were under development but which imposed on the engineer a severe manufacturing problem which at the present time had not been overcome.

If the 45 per cent efficiency was to be attained—it was a good target at which to aim—in addition to achieving the ability to operate at very high temperatures, they had to have extremely high component efficiencies for their compressors and turbines. At the moment those efficiencies were very good, but they had to keep that up and add another per cent or two. Also, it would be necessary to have compressors or compressor systems with a very much higher compression ratio than at present. There the designer of marine and industrial gas turbines was already well behind the aircraft people, for the aircraft people had compressors of a considerably higher ratio than those in current designs for industrial and marine engines.

Finally—he thought he had probably got to about 43 per cent now—they would require a good heat exchanger, too, although it might not have to be one of very high thermal ratio.

He thought that Mr. Lamb, Mr. Duggan and the rest of them saw the way to the high figure, but they also saw that they would not achieve it without a great deal of sweat and cerebration.

He was not qualified to make detailed comments upon the extremely interesting paper, and there were present persons who were far better fitted to do so than he was. However, it seemed to him that there was a most interesting period ahead and that for many years there would be most valuable and stimulating competition in the marine field between the Diesel engine and the gas turbine. They must not leave out of account the curious symbiosis of the two which was exhibited in the free piston type of plant which the French were installing in certain minesweepers and tugs. It was an interesting combination of a Diesel type of gas generator with a gas turbine. The three types would be in competition for some years to come, and in the last analysis the competition would be won by the one which showed best on the economic balance sheet.

MR. B. E. G. FORSLING, Civ.Ing. (Member), said the authors were to be congratulated upon preparing and presenting a very interesting paper which constituted a complete and most valuable description of the experience in service with the first gas turbine to be installed in a merchant ship.

Although Sir Harold Roxbee Cox had already dealt with the subject, he wished again to mention that the installation materialized owing to the foresight of Mr. Lamb, who visualized the potentialities of the gas turbine for the mercantile marine at a time when most shipowners considered it only as a future possibility.

The gas turbine set for the *Auris* had undoubtedly been successful inasmuch as it had achieved all that had been expected. The experience obtained, therefore, should lead to greater confidence in the gas turbine, particularly regarding reliability under ocean-going conditions, and so hasten its more universal application at sea.

Ship propulsion should be a particularly suitable application for the gas turbine. The use of oil as fuel was no drawback because even steam ships were using it today. There was, however, one factor to which he would like to draw attention; namely the size of propulsion sets required for the larger portion of the ocean-going tonnage was favourable for the gas turbine.

Merchant ships were today propelled either by Diesel engines or steam turbine machinery. Diesel engines were suitable for small and moderate power requirements up to, say, about 3,000 s.h.p. in service, or about 4,000 s.h.p. rated output. Although much larger engines had been built, the Diesel engine became increasingly unattractive when the size was increased beyond that limit. The present change from Diesel to steam propulsion machinery depended to some extent, undoubtedly, upon the increasing power requirements of ships. Steam turbine machinery, on the other hand, required large units in order to show up to its full advantage. 50,000 h.p. or more was desirable, for instance, before really high initial steam conditions could be justified.

The gas turbine, however, was suitable mainly for moderate power of, at present, about 3,000-8,000 s.h.p. The majority of ocean-going ships thus employed main propulsion units within a range of power where the gas turbine was attractive, but Diesel and steam machinery was above or below their respective optimum size.

In addition to reliability, the gas turbine must provide economical advantages in order to justify a shipowner's interest. Unfortunately, so many factors which influenced the economy were too uncertain to be put down in figures. As indicated in the paper, the gas turbine had today to be considered on its general prospects, which certainly appeared promising.

There was one aspect of gas turbine operation which had recently been in the forefront and was of great importance, namely the ability of the gas turbine to operate on low grades of fuel oil (residual oils), in view of ash deposition and corrosion. Experience with the *Auris* gas turbine set indicated that, provided the initial gas temperature selected was not too high, neither ash deposition nor corrosion constituted such serious problems as research work seemed to indicate. The magnitude of those problems depended, to some extent, upon the size of the gas turbine. The *Auris* had what might be called a small gas turbine. A larger set having larger blades and wider passages between the blades could obviously operate over a longer period before loss of material due to corrosion, and reduction of blade passages due to deposition, affected the performance to any appreciable extent.

That had been proved during the operation of a 2,500 kW. gas turbine which had recently completed testing at the Rugby works of the British Thomson-Houston Co., Ltd. The set was operated for some 300 hours on a residual fuel oil with a viscosity of 500 seconds Redwood I and a total ash of 0·04 per cent; that was to say, a light boiler oil which was burnt as received. During the test there was no falling off in efficiency either of the turbine or the set as a whole. The reduction of the effective flow area of the turbine was only about 1 per cent, which was just outside the accuracy of measurements. A gas turbine of adequate size should then, extrapolating the results, be able to run continuously for a considerable period, say, 1,000 hours or more, before shutting down for cleaning was required. If the deposit broke off or could be removed without opening the turbine, the marine service requirements were met.

The experience with that gas turbine set was similar, in some respects, to that obtained with the *Auris*; that was, the deposition on the stator blades was appreciably larger than that on the rotor blades, and although the amount of deposition was not sufficient to cause any break-off from the rotor blades, there was indication of partial break-off from the stator blades.

He agreed with Mr. Lamb's conclusion that there was no evidence that the grade of the fuel oil (viscosity) was of any particular importance. A higher grade of fuel oil—that was, having a low ash content—might require a longer time for the deposition to build up at first than a lower grade of oil with the same ash composition but having a higher total ash content, but operating conditions were otherwise likely to be fundamentally the same. The amount of ash which deposited on the blade was an extremely small fraction of the total.

Of the conclusions listed by the authors, he would particularly stress the emphasis on simplicity (No. 7) until more experience had been obtained. Such a complication as reheating, which involved adding an intermediate combustion chamber, should not be considered at present.

MR. W. KILCHENMANN, Dipl.Ing., said that he wished, first, to congratulate the authors upon the presentation of a most instructive paper. The information and observations therein were most useful, giving as they did a practical picture spread over two years of actual operation. That knowledge would undoubtedly influence future development of the marine gas turbine.

Mr. Lamb had been a pioneer in the use of heavy oil in Diesel motor ship installations, and it was interesting to see that he had extended his activities to the gas turbine field.

The authors had expressed the opinion that in the future, thermal efficiences in the region of 45 per cent could be obtained by gas turbines. It would interest him to know by what means that was to be achieved. A maximum temperature of about 1,000 deg. C., which was 1,835 deg. F., was required at the high-pressure terminal inlet, even assuming the best component efficiencies and with a complicated plant arrangement. For ship propulsion, however, one would sooner give preference to a somewhat simpler layout. If, in addition to that, no extremely optimistic assumptions were made for the component efficiencies of the plant, then a temperature of some 1,200 deg. C., or 2,200 deg. F., was necessary to obtain such high thermal efficiency. At the same time, attention must be paid to ensuring that the blade cooling did not give excessive additional losses. It would be interesting to know whether the authors visualized the possibility of building gas turbines for such extreme temperatures which were both simple enough and safe in operation? Further, the problem of burning heavy fuel oil was particularly difficult at those temperatures.

Opening the bypass valve caused the back-pressure at the high pressure turbine to fall, which meant a rise in the compressor speed at the moment when the opposite was required. Had any troubles occurred in running because of that?

Two over-speed cut-outs were mentioned as having occurred during severe gales when the fuel supply was interrupted. It would be interesting to know more about that. The problem of regulating the gas turbine when the propeller was out of the water required particular attention. Was it possible to regulate the turbine so that the fuel supply was never broken? In that connexion, it would be useful to know how quickly the installation reacted to the influence of the governor.

One of the most important aspects of the plant in the *Auris* was the combustion of heavy oil in the turbine. The operation of the vessel in that respect was pioneer work of the highest order. From the explanation of the authors, it appeared that the problem of burning heavy fuel had not yet been completely solved but that the ultimate solution should not be too difficult to achieve.

His firm had collected a lot of data on that subject. The conclusion had been reached that the difficulties to be overcome were greater than to be expected from the tests carried out on the *Auris*. Particular care had to be taken with fouling and corrosion as those rose almost exponentially with respect to the operating temperature and were also proportional to the concentration of the combustion gases. The development of turbines of higher output and economy would necessarily lead to higher temperatures and pressures than those in the installation on board the *Auris*. Consequently, the difficulties would be greater. Tests carried out on incomplete combustion by his firm prompted him to believe that the solution which had been adopted in the case of the *Auris* might well prove to be inadequate. Further, the formation of soft soot deposit always meant permanent danger of fire. The question had been raised as to whether the problem could not be solved by the use of suitable additives, and to that end very promising tests had been carried out. It was felt that that would be the safest way to solve the problem of burning heavy oil under the increasingly difficult conditions of higher pressure and temperature.

COM'R(E) J. F. S. WILSON, R.N.(ret.) (Member), said that one of the most comforting lessons learnt from the paper, to his mind, was the reliability of the heat exchanger. One had heard of rather elaborate construction in heat exchangers and of unwelcome fires in them, and the tendency was to feel strange in their presence. Yet there was one made of familiar material in a familiar form. No sea-going engineer could feel overawed by mild steel tubes of diameter and thickness approaching those of boiler tubes, suitably bent to allow expansion and fitted between drums. Interest and hope were there from the start when he realized that he could limit deposits by soot blower, wash it easily, and test and plug indivdual tubes.

Confidence must follow the length of service of 11,000 hours. Whether it entered directly or indirectly, there was a spirit of good British boiler making about the job which boded well for the future, for that spirit would not sleep easy at 52 per cent efficiency, nor in its struggles to improve that figure cease to picture the senior second and his team battling valiantly with maintenance far from home, nor yet would it be dismayed when the gas turbine demanded a heat exchanger to withstand six or even twelve atmospheres instead of the three needed in the present case. Even if more expensive materials and more elaborate construction won the day, a standard of wholesome reliability had now been set.

The very long time allowed for cooling the turbines and the distortion even to gripping point which was apparently liable to occur during that period made him wonder whether there would be danger of damaging the turbines if the set had to be restarted at any time before they were cooled. If so, a serious handicap was indicated. Perhaps the authors would say whether any method had yet been tried of ascertaining whether distortion was likely to be below or above the danger level for restarting. He was thinking of some simple guide pointer such as the temperature at the turbine discharge duct, or even a time limit. He imagined that the refractory in the combustion chamber accounted for a very large amount of the time allowed for cooling the turbines, and he would be glad if the authors would confirm that.

He noticed that a clear and practical routine had been established for washing the compressor blades both with paraffin and with Teepol and water, but that in each case it was carried out while the engine was being turned by the starting motor. He had occasionally seen the washing carried out on a gas turbine while it was on normal running, though at low power to allow some latitude for increase in compressor turbine speed, and he wondered whether that operation could not be carried out in the turbine under discussion while it was under way, either at regular intervals or when instruments showed that the compressor efficiency was falling off.

In a previous description of the engine, mention had been made of a photo-electric cell to cut off the fuel if the flame inadvertently went out. It would be interesting to know if that had ever occurred, and if so, in what circumstances.

MR. LYDER KAHRS said that he was expressing the opinion of many in his country, which was certainly a sea-going nation, when he congratulated the authors and their associates on the research achieved with the *Auris* set and upon the paper, which described the research in a very practical manner. Much was due to the fact that the authors combined a practical experience in operating ships with fuel technology and knowledge and interest in the new prime mover. It was felt in Norway that this enterprise had reduced by several years the period before which the gas turbine would be in common use at sea.

He wished to ask a few questions connected with the paper. First of all, with regard to fuel deposits, some reference had been made to the places where it accumulated. He wished to know whether the authors had any idea if the length of the flow path had anything to do with the matter and if the raising of the turbine temperature would influence where the deposits would collect.

Furthermore, he wished to ask whether the recommendation of a turbine inlet temperature of 1,200 deg. F. was based on the feeling that that was as far as their present experience carried them, or whether there was some other reason.

MR. I. G. BOWEN said the authors had indicated the criteria which a marine gas turbine had to fulfil, and if permitted the liberty, he would underline some aspects of the problem of keeping the turbine free from deposits. To the marine user, availability of the turbine for long periods was an essential, and there were some present at the meeting who regarded ash deposition as an obstacle to the gas turbine's progress.

Early during the year, Bowden, Draper and Rowling* had summarized their findings on the experimental engine at C. A. Parsons and Co., Ltd. Briefly, they were as follows: With combustion conditions in which all the carbon was burned, the Parsons turbine suffered a very high rate of ash deposition. If the combustion conditions were altered to produce a sufficient quantity of what were known as "stack solids", then the turbine was kept free of deposit. A second solution to the problem was also found. The introduction of additives to the fuel oil produced a reduction of deposition for periods of running up to thirty hours. The most promising additive was silica added to the fuel in soluble form, and the suggestion came from Sulzer, who found a reduction in deposition with that element in both rig and engine tests.

In the postscript to the paper the authors had described

* Bowden, A. T., Draper, P., and Rowling, H. 1953. "The Problem of Fuel Oil Ash Deposition in Open Cycle Gas Turbines". Presented at a General Meeting of the Institution of Mechanical Engineers on 24th April 1953.

their recent experiences with heavy fuel oil. With a normal residual fuel oil containing 0·07 per cent ash, the ship crossed the Atlantic with a reduction of turbine area of 5 per cent in 500 hours, which corresponded roughly to a 10 per cent loss in power, allowance being made for change of ambient temperature. Making no allowance for ambient temperature, the loss of power was even greater and it became clear that the problem was a real one.

The stage was now set to perform a full-scale trial, and on the recent round trip to Curaçao three separate tests were carried out. A fuel of very high ash content—0·12 per cent—was chosen. The first run was on the existing build with no attempt made to produce stack solids. The result was a very rapid build-up in deposit. In seventy hours the turbine area was reduced by 21 per cent. After shutdown, during which a good deal of deposit fell off, that test was followed by one in which atomization was coarsened by reduction of fuel temperature, in order to produce stack solids. The test ran for 140 hours, and the turbine area steadied after 100 hours to a value of 8 per cent below that at start-up. On the return trip from Curaçao a silica additive test was conducted, but without the assistance of increased stack solids. After some initial difficulties in handling the additive, a continuous run of 94 hours was achieved in which the turbine area *increased* by 4 per cent.

It was clear, therefore, that having succeeded in applying stack solid and additive control of ash deposition on three different engines, the chances for the future in other engines were very promising. There were still many problems to be solved, and it was not immediately obvious whether combustion control or a solution by additives would in the long run be the more effective.

MR. P. DRAPER (Associate) said that he wished to add his congratulations to the authors, not only for having presented the paper but also for their courage in risking their established reputations by recommending the use of that interesting, and even exciting, new form of engine. That their courage had been well rewarded had been proved by the paper which the meeting had heard.

The paper was mainly a statement of operating experience over the last two years and, as such, was most encouraging. Although in his opening remarks Mr. Lamb had said that he felt that he should avoid doing so, he wished that Mr. Lamb had after all given them some indication of the likelihood of the economics of gas turbines being satisfactory in the future.

In that connexion, he had assembled a few operating figures and made an estimated comparison between the running cost of an existing type of propulsion unit and a gas turbine of present-day design. Since steam turbines were generally selected for propelling modern tankers, this type was taken for comparison.

Considering 7,500 s.h.p. in each case and a tanker duty of ten round trips per year, each of thirty days' duration, the following estimations had been made:—

	Steam turbine	Gas turbine Electric
Specific fuel consumption for all purposes, lb. per s.h.p. hr.	0·6	0·5
Fuel consumption, tons per day	48	40
Lubricating oil consumption, gallons per day	Negligible	Negligible
Periods between overhauls, in months	12	12
Overhaul times, in days ...	16	10
Maintenance required at end of each round voyage of 30 days, in days	3	2

Assuming a fuel cost of £8 per ton, then a comparison of costs per annum of those items which were affected by the type of prime mover might be estimated as follows:—

	Steam turbine £	Gas turbine Electric £
Fuel cost at £8 per ton ...	115,000	96,000
Overhaul and demurrage at £1,000 per day	16,000	10,000
Maintenance at £400 per day	12,000	8,000
Total	143,000	114,000

No item had been included relative to first cost as it had been felt that no reliable data was available. The above comparison might be considered conservative, yet a considerable saving would be indicated in favour of a gas turbine unit.

Turning to the more technical aspects of the paper, he wished to emphasize a few of the points made, but first of all he wished to suggest a correction. In Table IV on page 288, the marine Diesel fuel was stated to have an ash content of up to 0·06 per cent by weight, but since marine Diesel fuels seldom had an ash value in excess of 0·02 per cent, he thought there had been some admixture of the Diesel fuel with the heavy boiler fuel used in the preceding months. Perhaps the authors would say if that were likely.

Concerning combustion and combustion chambers, he was very pleased indeed with the outcome. He understood that the smoke had been very light and that the carbon formation in the combustion chamber had been practically nil. Slagging or spalling of the refractories in the primary zone had been negligible—one might even say non-existent—and a life of over 11,000 hours on those self-same refractory bricks right through was a staggering performance.

He believed that the main reason for that success was the closely controlled flame shape, which was tailored to fit the combustion chamber without touching it. He also believed that the sight windows briefly referred to in the paper had been of inestimable value in enabling an off-centre flame to be spotted and at once rectified. He considered such windows placed in the axis of a combustion chamber to be absolutely essential and would also put in a plea for other windows not included in the B.T.-H. design to view the inlet guide vanes of the h.p. turbine, as it was most instructive to watch such a critical portion of the engine's anatomy.

MR. I. LUBBOCK said he would not take up a great deal of the time of the meeting because he was not in a position to embark upon a general review of the gas turbine for marine propulsion. He could only deal with the combustion problems because he happened to have been associated with the design of the system.

At the time the problem was brought to him, most experience of combustion under pressure in a gas turbine had been obtained with the aero gas turbine, of which he had considerable knowledge, and it was considered that his efforts would be immediately successful. He did not know why, but that was what everybody seemed to think. The system, which had been adequately described, was produced on the drawing board and put into practice. It was now about five or six years since it was put down on paper. One of the things which he had had to decide was how to obtain long life in the combustion chamber.

It would be noticed that he had chosen refractories, much to the amazement of quite a lot of people who thought that that was one of the most serious and risky things to do. It probably was risky, but one could not make progress without taking risks, and while for many years he thought of the horrors of pieces of refractory falling off and stripping the turbine, it would be noticed that after all that long running nothing of the sort had happened. Similarly, nothing had happened over a number of other parts of the gas turbine. There, he thought, the authors had to be congratulated, particularly Mr. Lamb, upon taking risk and doing that work, where so many things had to be settled in actual practice at sea. That was the really trying test. The refractories were not held in like bricks in a flue—they had not been fully described, but there was no need to describe them in great detail—but were cunningly arranged like suspended arch segments on supports.

As to the future of combustion chamber design, he could only express views from his experience. There were two combustion chambers, and they could have had one. In some of their developments for locomotives, the Americans had rather tended to continue the aero engine practice of a multiple series of just metal combustion chambers. There was, of course, a lot to be said for just the simple metal "can", as it was called in aero practice, and there were many conflicting views on whether one should have one large combustion chamber or two or three or more smaller ones. In the present case the choice had been two. He really was not sure whether that was the best solution or whether it was worth while multiplying them by more than had been done.

The problem of burning inside an engine was not the same as that of burning in a boiler. In the case of a boiler, one could take the burners out and clean them and put them back again. However, one could not do anything once the engine had been set under way, and that explained why progress on altering the combustion system as they went along was slow. They had to bide their time and do the alterations whenever they could. In some of the designs produced at the time, there were depressurized gates so that the burners could be withdrawn while the engine was running, but the load thrown on the other combustion chamber did not make for very happy running.

On the question of the primary zone condition, to which the authors had referred, a great deal of work still had to be done to ascertain what caused the best combustion conditions and what did not. Only the previous Friday he had listened to a very learned young man who worked it all out by chemical kinetics and the activation energy of the molecules, and he proved fairly conclusively to all concerned that the rating of a combustion chamber should be so many B.Th.Us. liberated per cubic foot per atmosphere squared, not per atmosphere. In other words, one should find it very much easier to burn fuel under pressure than one would at atmospheric conditions. There was one case, anyway, where it was proved rather more difficult to burn fuel under pressure than under atmospheric conditions. It only went to show that theory could go only part of the way. The rest, he was afraid, was still an art.

Similarly, there was the question of what should be the percentage of primary air. Again, the learned young man with the kinetic theory proved—he did not say that he was wrong; it was puzzling—that it should be richer than stoichiometric and that 30 per cent excess should be added further down the combustion chamber. The authors told them that they got the most marked improvement by raising the excess air from some 60 per cent to 100 per cent. So they still did not quite know how to burn oil in a combustion chamber and were still faced with the problems of multiple combustion chambers and multiple burners, apart from the others which came at the other end when the fuel had turned into waste gases and had proceeded down the system.

MR. J. F. ALCOCK said that he had noticed that the experience with the heat exchanger was that the deposits were thin and easily removed. The size of a heat exchanger, other things being equal, was more or less proportional to the diameter of the tube in use or the width of the passage in any other form of heat exchanger. He wondered whether the authors, now that they had that experience would, if they were starting from scratch, go to smaller tubes, such as ½ inch instead of 1 inch, and thus considerably reduce the size and weight and, to some extent, the cost of the heat exchanger.

MR. N. E. THOMPSON (Member) said that some time ago when he was in Switzerland he had the opportunity of examining a rather large gas turbine plant which was installed in a power station. He was rather appalled to see the size of the equipment there, and it rather put him off the gas turbine. However, after hearing the paper and the discussion he felt that it was certainly a type of machinery which would come into its own.

It was very nice to see that the consumption of lubricating oil was so low, and the fact that Mr. Lamb's directors had sanctioned yet another ship of even greater power showed that the directors were satisfied with the first experiment. The directors were the principal people who had to be satisfied. As he had to deal with directors also, it would be very useful if the authors could provide a comparison of initial costs between a vessel engined by steam, a vessel engined by Diesel and a vessel engined by gas turbine.

The authors would do the Institute and the marine engineering industry a great service if they presented a further paper after the operation of the larger vessel.

CAPT.(E) H. F. ATKINS, R.N., said that he congratulated Mr. Lamb and everybody concerned upon a most marvellous achievement, but he wanted to raise one note of question.

Were they on the right lines at all? There were two lines of attack on the marine gas turbine. One was the aircraft engine approach and the other was the steam turbine approach. The one under discussion was the steam turbine approach. As far as he could see, that was why they got into the troubles of having to turn the engines for hours afterwards, the distortion of the turbines and so on.

Before they went too far on those lines, they ought seriously to consider whether, as marine engineers, they would not do better—he was a bit of a renegade; he was a marine engineer but had been employed in a gas turbine establishment for the last two and a half years—if they adopted the aircraft approach rather than the steam turbine approach. He did not like the fancy bearings of the aircraft people instead of the plain journals, but apart from that there was a great deal to be learnt from the immense amount of effort which had been put into the aircraft engine, and if they designed their turbines on steam lines they would be throwing away a lot of that work.

Another thing which appalled him was the refractories. He loathed and detested refractories. They were the major headache in the Navy during the last World War. One could say that categorically. If one got water in the fuel—he had no doubt that the oil companies managed to keep the water out of the fuel, but they did not in the Navy during the last war—one would get the refractories fluxing just as they used to in the boilers, and then where would one be? If they could get away with Nimonic, let them stick to it, adopt the aircraft practice and say a fond farewell to refractories for ever.

Correspondence

MR. JOHN BULMAN (Member) considered the paper to be of particular interest in that it gave the first authentic information regarding the prolonged operation of a gas turbine in a merchant vessel under normal conditions at sea and the authors were to be congratulated on the comprehensive and detailed account they had given.

The *Auris* was, of course, an ideal test bed for such an experiment since even a major breakdown of the gas turbine did not hazard the ship, but it must be most rewarding for all concerned that no such breakdown had indeed occurred. A great deal of the credit for this must go to the designers and builders of the set but there must also have been marked ability and attention to duty on the part of the operating personnel and it would be interesting to learn how much special training they received before taking over the new machinery. From a technical standpoint, however, the information given in the paper showed that the gas turbine could be a reliable proposition for marine propulsion and the importance of this fact alone far outweighed any minor difficulties which might have been encountered.

As was perhaps foreseen, the chief obstacles to complete success appeared to have been the interwoven problems of imperfect combustion of the fuel itself, deposition of the products of combustion on the blading and the resulting possibility of corrosion. Though some progress in these respects appeared to have been made during the period under review, it could not be regarded as fully satisfactory that "the loss in efficiency due to deposit on the h.p. turbine blading is about 4 per cent after sixteen days continuous running" (page 286). Even though the deposit was said to break away of its own accord when the set was shut down, examination of the single set of voyage records provided showed a deterioration in overall performance of about 7 per cent in ten days' running (25/6/52 to 4/7/52) with a corresponding increase in the fuel bill. It might be that considerable improvements in this direction had been made since these voyage records were taken but the figures as they stood did not seem to justify the conclusion that "there is no reason why future gas turbines should not operate efficiently and continuously on the longest voyages". The authors' views on this would be of considerable interest.

Apart from special applications in which weight and space were of particular importance, the attraction of any form of marine propulsion machinery lay in a combination of low first cost, high reliability and low fuel consumption. Considering these factors in relation to the gas turbine, the first cost of the installation must vary widely for different applications and need not be considered here. The problem of reliability measured as the capacity of the machine to continue to deliver a reasonable percentage of its rated power without excessive maintenance appeared to have been solved in the *Auris* even though there were inevitably a number of minor routine tasks which must be undertaken at the conclusion of each voyage. This form of reliability had been achieved, however, at the expense of fuel consumption and it was in this direction that advances must be made. The obvious method was by increasing the temperature range over which the machine operates and here the authors did well to sound a note of caution in their conclusions. On the other hand, despite the development of new materials, there could not as yet be sufficient experience available for the type of cycle adopted in the *Auris* to warrant the earlier statement that the gas turbine "will in the not far distant future compare favourably with the Diesel engine in the matter of fuel economy".

Nevertheless, the owners of the *Auris* and the designers and builders of the gas turbine fitted in her must be congratulated on having taken a real step forward in marine engineering. They had, in fact, shown that if the particular conditions of operation justified it, a gas turbine suitable for marine propulsion could be produced and operated in normal service and this proof must inspire them and others to further efforts towards improving the efficiency and thus broadening the field of application of this type of prime mover.

MR. F. J. COLVILL (Member) wished first to pay a tribute to a pioneer and his assistant and to say what pleasure and satisfaction he was sure they all felt in the achievement of their distinguished fellow member of the Institute.

In 1950 he had the privilege of witnessing some demonstration trials on the River Thames of a 60-foot launch driven by two small high speed gas turbines. That launch was the *Torquil,* the first craft, he believed, to be wholly propelled by gas turbines, and fitted with two of the Rover 100-b.h.p. engines. The installation was a very simple arrangement of an air compressor, combustion chamber and gas turbine, for each of the two sets and was, therefore, very inefficient.

When he saw the gas turbine for the *Auris* on the test bed, the difference was very marked; here they had the next rational step in the adoption of the gas turbine to merchant ship propulsion. He said "rational" because Mr. Lamb, from their knowledge up to date of thermodynamics, could have arranged for a much more theoretically efficient turbine installation, but being an experienced marine engineer and a wise man he followed the advice given in "Conclusion No. 7" of this paper, namely, that the emphasis should be on simplicity of construction until more experience had been gained under arduous sea conditions.

With regard to the advantages which the gas turbine had to offer, he would venture to say that it had yet to be determined whether in general the amount of overhauling required over the life of a ship would be less than with other types of machinery. If they remained satisfied with a fuel consumption greater and an efficiency consequently less than that of the Diesel engine, the answer even at this early stage would, he thought, be yes, but the installation became more complicated the higher the efficiency aimed at.

With regard to the authors' contention that the time had come to supply all cargo requirements with power produced by the propelling units, this presupposed electric drive or direct drive with a subdivision of main units, one or more of which could be used to drive power generating machinery for supplying cargo handling gear. Now, although it was over twenty years since electric drive was first adopted in an ocean-going British ship, comparatively few such ships had since been ordered by British shipowners, who presumably were influenced mainly by considerations of cost, initial and running.

Did this not point to the probability that direct drive and the usual method of supplying auxiliaries including cargo handling gear, by an independent source of power, was more economical in the long run, at least for many ships. He was inclined to believe that if a reasonably economic method of reversing the drive to the propeller were forthcoming, that would prove more attractive with gas turbines than electric drive.

The information so generously given in this paper on the experience of running the gas turbine of the *Auris* over the first two years of its service life was absorbingly interesting and few of them would be prepared to question the reasonableness of the ten conclusions.

He was particularly pleased to hear of the successful reduction of noise from the set, as he came away from the B.T.-H. test house rather throaty from trying to talk to acquaintances, and with a noise in his ears. He understood that the noise of the turbine was now almost completely drowned by the noise of the Diesel engines in the engine room of *Auris.*

One of the aspects of the advent of the gas turbine in ships with which the Ministry of Transport was concerned was, of course, the fire risk. How simply a fire could be started where parts of an engine run at very high temperature and lubricating oil was involved was well illustrated by the experience described on page 005 of the paper. Would the authors be good enough to describe how the fires were quickly put out? He would like to point out that they had not had with other types of machinery any risk of lubricating oil fires, apart from crankcase fires and explosions from Diesel engines, which was an entirely different consideration. In the gas turbine there were in close proximity very hot engine parts and lubricating oil in pipe leads and bearings and it was as well that the risk should be generally appreciated.

As far as the oil burners and the hot gases therefrom were concerned, he saw no more fire risk than from similar combustion arrangements on oil fired boilers, except that with the gas turbine there were fairly large very hot surfaces and numerous joints. He did not want to appear alarmist or to stress unnecessarily any hypothetical danger aspect of this new type of machinery, but he had been puzzled by the reports in the Press, from time to time, of a jet aeroplane exploding while in flight, no explanation of the cause being made public. They were all aware of the dangerous nature of vaporized hot oil and it was as well to remember that low pressures and relatively light scantlings were involved in the gas turbine and that vaporized hot oil in certain circumstances could be present. So the necessity for ample safeguards against those circumstances arising must be realized.

The Diesel engine had been running in ships successfully for many years before the necessity of certain safeguards, not hitherto provided, were recognized as necessary and this only as the result of a disastrous explosion with very distressing results.

On page 284 of the paper the authors referred to the difficulty of removing nuts on the h.p. turbine and combustion equipment. Probably the temperatures might be too high for the use of aluminium spraying of the threads, but this was successfully used on high temperature steam turbines.

He noted in connexion with deposits on the turbine blades that the method adopted to remove that which did not shed itself was by individual manual scraping, which took two men twenty-four hours to clean the 1,100 blades. Could they be told how often this thorough cleaning was considered necessary in view of the statement that the 4 per cent loss of efficiency from deposits in the h.p. turbine was regained by complete cooling down. Had the authors considered removal or loosening of deposits by application of a high frequency vibrator which was claimed to be capable of removing scale from the heating surfaces of boilers?

Apparently a gradually increasing loss was experienced due to deposits which could be 4 per cent in the turbine and 4 per cent in the compressor after sixteen days' running. Presumably the resulting aggregate loss would be of the order of 6 per cent. Was this gradual loss reflected in a corresponding increase in consumption or in a reduction of output?

As one might expect, the burners and combustion chambers which had to stand up to such severe conditions had required various amendments and adjustments and it was interesting to note that when nature rebelled it occasionally put right the errors of man, though not very often in the engineering field. He referred to the burning away of the entire shroud lip referred to on page 289, resulting in the unusually short flame desired which gave a lead to the sort of amendment required.

The authors were to be congratulated on the very full and interesting paper, which formed a distinct milestone in the progress of marine engineering and was some indication of the rewards possible from research, the necessity of which this country, fortunately, now realized to the full and, although they had perhaps a long way to go before the 45 per cent thermal efficiency mentioned as their "not too ambitious" aim by the authors, they had every reason to be optimistic with regard to the future of the gas turbine for marine propulsion.

MR. A. HOLMES FLETCHER, B.Sc.(Eng.) had had the honour of presenting a paper* to the Institution of Mechanical Engineers some time ago, in which he advocated the use of aeronautical techniques in the design of gas turbines for marine use. He had received rather rough treatment in the ensuing discussion at the hands of the advocates of "heavy" style engines and could not reply effectively at the time because of the secrecy regulations applying to the engine on which he had been working.

Now that this engine had been placed on the open publication list, he could give some facts about it and its operation which would provide an interesting comparison with the information which the authors gave about their experiment, on the success of which they were to be congratulated, and with the developments which they foreshadowed.

He referred to the Rolls-Royce R.M.60 naval turbine, which was now being installed for sea trials. This engine weighed 5lb. per s.h.p., including all auxiliary machinery, filters, starter, thrust bearing, mounting frames, control systems, etc. It could be started from cold within fifteen seconds and opened up to full power within three minutes. Power variation from idling to full and *vice versa* was at present limited to a minimum time of one minute, but schemes were available to increase the rate considerably. It was not necessary either to motor over or circulate oil after shutting down. This latter property could be argued to be due to the use of ball bearings on the main shafts, but judging from the temperatures recorded it should be quite possible to retain it even if plain bearings were to be employed. The engine gave a specific consumption of below 0·65lb./s.h.p. hr. from 25 per cent power upwards, but its heat exchanger was a relatively small one and was practically bypassed at full power, which was acceptable for naval purposes. Designed for merchant ship application, the consumption at full power would be greatly improved to something like 0·5lb./h.p. hr., which was more in keeping with the 18½ to 1 compression ratio and the 1,500 deg. F. combustion temperature employed.

With these facts in mind, some interesting points arose in regard to the *Auris* machinery and heavy turbines of this type in general.

Firstly, the authors made some mention of the arguments which led to the designing of their turbine for ahead running only, reliance being placed on the Diesels for manœuvring. It seemed that first cost was one of the major factors, but it was not clear why, with electric transmission, providing ability to manœuvre with the turbine would have involved any great expenditure. Was there another reason which they did not mention? Were they nervous of the ability of the heavy gas turbine to withstand the sudden temperature changes involved in manœuvring? Had they now sufficient evidence to show that the 8,300 h.p. Anglo-Saxon tanker set would be satisfactory in this respect, or were manœuvring Diesels still to be incorporated? How did they expect the suggested 5,000 h.p. design weighing 74lb. per h.p. to behave?

The R.M.60 tests had shown that an "aeronautical" design was adequately flexible for manœuvring, although it must be admitted that this engine did show an unexpected limit on the rate of deceleration owing to the tendency of the two compressor shaft systems to get out of step, owing to their greatly differing inertias, and cause violent surging, which had proved to be an obstacle in the way of meeting naval requirements for reduction in power and reversing from full ahead.

In the case of the authors' proposed 5,000 h.p. turbine, when they stated that intercooling between two compression stages would be employed in order to improve efficiency, presumably the avoidance of low-power surging would lead them to use a two-shaft design. If, as in the case of the *Auris* turbine, these rotors were so massive as to be able to run on for twenty minutes after shutting down, one might expect the limitation on the rate of deceleration to be much more serious than on the much lighter R.M.60.

Perhaps this manœuvring question is being laboured too much. Personally, he had experience only of naval requirements, and suspected that a tanker would not require anything like the manœuvring ability of, say, a frigate. Could the authors give an indication of the telegraph order sequence and duration of each condition which might be expected in leaving harbour in one of their vessels?

Regarding the question of efficiency, the R.M.60 consumption was given in terms of power at the propeller shaft. Did the authors' figures similarly include transmission losses? If not, what were the comparable figures for the actual and projected designs? When transmission loss was included, and allowance was made for hotel services and other auxiliary power, did the authors still think that the gas turbines would show enough advantages from reduced maintenance, etc., to justify their installation in competition with large Diesels or steam machinery?

* Fletcher, A. Holmes. 1952. "The Marine Gas-turbine from the Viewpoint of an Aeronautical Engineer", Trans.I.Mech.E., Vol. 166, p. 237.

It was noteworthy that the authors made a point of using boiler oil in their future gas turbine projects. One of the arguments raised in connexion with his own paper was that at the temperatures he was proposing to use it would be essential to burn distillate fuel, when the increased price would put his tentative design of engine out of consideration. It was pointed out that in view of the established efficiency of existing machinery and the price differential of the fuels, a turbine burning gas oil would have to give an efficiency much better than anything which the authors now visualized in order to be competitive, even when extra carrying capacity and reduced maintenance costs were included.

A recent article in the Press, however, suggested that with the increasing use of catalytic cracking at the refineries there was likely to be a diminution of the supply of boiler oil and an increase in quantity of distillate fuels. Might he ask for the authors' views on this possibility? If residuals were actually likely to be withdrawn from the market, would they not be wise to consider again the use of higher combustion temperatures, when an "aeronautical" design became better suited to the conditions?

The sensitivity of the gas turbine to variations in ambient temperature appeared to be much greater than in the case of other prime movers. Table I showed that a rise in intake temperature of 34 deg. F. caused a fall in output of over 30 per cent, which was sufficient to make a marked reduction in the speed of the vessel. Was this liable to cause any misgivings? Would future turbines be designed to tropical conditions with a limiting device incorporated to hold the power to this figure when temperatures fell, or would the transmission be designed to cater for the maximum power available under arctic conditions?

The authors were again to be congratulated on their faith in the future of the gas turbine, implicit in their belief that thermal efficiencies of 45 per cent would be attainable eventually. Such a figure was only possible if combustion temperatures were raised and if a more effective heat exchanger were incorporated, as there would appear to be little scope for improvement in component efficiency over the figures achieved in the B.T.-H. design. Compounding would also be necessary. The increased temperature would probably lead to the use of stainless instead of mild steel and a considerable increase in capital cost would arise. Had this point of view been considered?

MR. W. F. JACOBS (Member) wondered whether it would be possible for the authors to add some details of the handling of the turbine plant under manœuvring conditions, such as hanging about in order to pick up the pilot, working the vessel alongside, and procedure when the personally-detested message from the bridge, "Don't know when we will shift but keep her handy", was received.

In regard to the question of development, from the verbal discussion it seemed that higher inlet gas temperatures might be called for despite paragraph (6) on page 280, and on page 278 it was mentioned that some form of blade cooling had yet to be achieved. This seemed rather strange in that if the blades were cooled the incoming gases would be cooled and, therefore, contract, thus actually reducing the efficiency to that achieved if the gases were admitted at the temperature they were cooled to by the cooled blades.

Might it be possible to have two h.p. turbines on the same shaft and a changeover valve admitting hot gases to first one and then the other, the one not having the hot gases being supplied with a smaller amount of compressed air from the compressor? In this case some regenerative effect might be achieved as the section of turbine supplied by air only would part with the heat of the blades to the air, which would expand and give out some of the heat as work.

It might be a source of economy if the incoming air to compressor were heated by the "exhaust" leaving the heat exchanger, passing through another heat exchanger placed in the air intake from deck. Less fuel would thus be required to bring the gases to the temperature required though, of course, a somewhat larger compressor would be needed.

The pressures were very low and it seemed likely that an engineer with experience of oil firing and turbines should soon be conversant with the plant, despite some trouble due to the high temperatures at the turbines.

MR. T. M. B. MARSHALL wrote that as one speaker had indicated that one of the factors militating against the use of heavy fuel oil in future gas turbines was that of high temperature corrosion by components of the fuel oil ash, it seemed opportune to put forward some remarks on this subject.

It had already been mentioned that there might well be methods available for alleviating the problem of ash deposition by controlled combustion or by the use of additives. It was very probable that serious corrosion by fuel oil ash constituents did not take place in the vapour phase and it was, therefore, not unlikely that if a complete cure for ash deposition could be found this, in itself, would reduce high temperature corrosion very considerably. Recent work which had been carried out had indicated that some of the additives recommended for reducing ash deposition also had a marked effect in reducing high temperature corrosion while others which had been tested did, in fact, have a beneficial action in reducing this corrosion, although their effect might not be so marked on ash deposition. He would like to assure members that some workers were giving a great deal of attention to this problem and considered that the picture was not quite so black as had been painted.

While on this aspect, perhaps a word of warning should be sounded on the so-called "crucible tests" where a small piece of metal was exposed to the action of a large volume of molten ash. While such a method was, no doubt, of value as a "screening test", it would obviously be far from conditions obtaining in practice where normally such a severe state of affairs did not exist. Such tests, therefore, tended to give a rather exaggerated idea of the extent of corrosion to be expected.

Quite apart from the above considerations, their work had indicated that certain alloys had a considerable resistance to attack from molten ash constituents at high temperatures and it was not outside the bounds of reason that further advances in metallurgy might well produce even more resistant alloys. It should be realized that although any method of countering this problem might not itself give a complete answer, it was very probable that if several counter measures could be applied together, a complete solution might well be possible.

MR. A. W. POPE considered that to those engaged in work on marine gas turbines, each instalment of the *Auris* saga yielded fresh operational experiences of immense interest. In this paper, the authors had given in full measure data on such diverse subjects as compressor and heat exchanger cleaning, and the cracking off of turbine deposits, etc.

It was a pity, therefore, that one could not agree with the philosophy behind the mechanical design of the engine. There were several objections to the heavy form of construction, such as the excessive weight penalty, the difficulty of keeping the high temperature casings free from distortion, and the inability of such a set to accept sudden rapid load changes. It might also place an unnecessary limit on the raising of the turbine inlet temperature, which was one potent way of raising the efficiency of gas turbines.

Several successful long life engines had been built with the alternative approach (sometimes called kinetic design) and, in particular, the Allen 1,000-kW. set ran for 1,000 hours at various loads, including many hundred sudden large load changes, and the tip clearances were within 0·002 inch of their initial values. It had been argued that the heavy multistage components associated with this engine exhibited exceptionally high efficiencies. This was hardly true today of turbines (the most important components) and was doubtful of compressors. In view of this, the specific weight figure of 74lb. per b.h.p.

mentioned by the authors as a target, was very disappointing, and could be radically reduced.

It was a pity also to perpetuate a form of engine which did not lend itself to future development, i.e. to increasing the turbine inlet temperature. With the advent of Nimonic 90, and a better understanding of disc cooling, long life engines could now be designed to use temperatures in excess of 650 deg. C. It was worth giving consideration to the idea of regarding the engine proper as having a normal marine engine life, but replacing the first turbine wheel (plus blades) after, say, 3 years' use, rather than derating the whole engine to suit this one component.

Apart from increases in thermal efficiency, the use of high temperatures produced a significant increase in specific output, so that the current values for capital cost and specific weight should be considerably reduced.

The fact that the gas turbine could now only operate on heavy fuel at low temperatures should not be allowed to disguise or mask its real potentialities, many of which were entirely associated with the use of high temperatures.

It would be interesting to know whether the authors considered the existing and projected design to be mechanically suitable for future development.

DR. D. M. SMITH thought the authors were to be congratulated, both on the value of the development they reported and on the full and frank way in which they presented their experiences. It was remarkable that, in this first application of gas turbines to propulsion of a merchant ship, such reliable operation and low maintenance should have been experienced in two years' commercial service. The simple and robust design of the gas turbine plant had been fully justified by its freedom from operating troubles.

In the light of his experience in gas turbine fields outside the merchant marine, the writer would generally concur with the authors' conclusions but would especially emphasize the advantages of mechanical drive. For naval boost gas turbines, where the question of reversing did not arise, direct mechanical drive was the established method. The lack of an established means of reversing in the higher powers had, however, delayed the application of mechanical drive to main propulsion gas turbines.

Authors' Reply

The authors were appreciative of the opening remarks of Sir Harold Roxbee Cox, which justly claimed that Great Britain was well to the fore in the development of the gas turbine for all forms of transport. If the *Auris* experiment had contributed to such a desirable state of affairs, the authors and their employers, who made such an experiment possible, had achieved their aim and were encouraged to continue their endeavours.

As Sir Harold reminded them, the thermal efficiency of the marine gas turbine was less than that of the marine Diesel engine, but not, the authors would point out, to the extent stated. In the case of the 18,000 d.w. ton 15-knot oil tanker now being constructed and referred to in the paper, the gas turbine propelling machinery would have a thermal efficiency of at least 28 per cent, which was certainly more than half that of the most efficient Diesel engine, while the overall efficiency, which included maintenance costs and off-hire periods, in addition to the fuel bill, was confidently expected to be less than that of similar ships propelled by either Diesel engines or steam turbines.

The size and speed of the new gas turbine-driven ship had been selected because there would also be in service exactly similar ships propelled by both geared steam turbines and steam turbo alternators. Thus it would be possible to make an accurate comparison of not only the thermal efficiencies, but the overall efficiencies, which was what really mattered to the shipowner, of these types of propelling installation. A similar size of ship, although slower and propelled by Diesel engines, would also enter into the analysis which would follow in due course.

Mr. Lamb said that Sir Harold had taken him to task for setting the thermal efficiency target of the gas turbine at 45 per cent. He was not surprised, as no doubt such a figure might seem high in the light of past experience, but to those in constant touch with present-day developments and the improved results being obtained almost month by month with heat resisting and corrosion resisting steels and the beneficial effects of fuel additives, as well as the near approach of artificial cooling of blades, better utilization of waste heat, to mention only a few, the target of 45 per cent was not considered too optimistic.

The authors agreed with much said by Mr. Forsling who, as the designer of the B.T.-H. turbine had every reason to be satisfied with this first attempt. They felt, however, that he was being rather unfair when he stated that the Diesel became unattractive for powers beyond 4,000 b.h.p. and that in the case of the steam turbine powers of 50,000 s.h.p. were desirable before the full advantage of this type of propelling installation was obtained. Actually, Diesel engines were attractive from the point of view of weight and space occupied up to 7,000 b.h.p. and a steam turbine installation of upwards of 10,000 s.h.p. returned an attractive fuel economy when compared with present-day standards.

Mr. Forsling's remarks upon ash deposition and corrosion being of less importance in higher powered gas turbine sets which had larger blades and wider passages between the blades implied that he was prepared to accept fouling and corrosion when burning residual fuels. This was not the view of the authors, who felt confident as a result of experience gained since the paper was written that both loss of performance due to ash deposition and blade corrosion would ultimately be eliminated.

Mr. Kilchenmann also questioned the authors' views regarding the ultimate thermal efficiency of the marine gas turbine. When setting a target of 45 per cent it was confidently expected that both metallurgical and combustion difficulties would be overcome within the foreseeable future. The turbine inlet temperature, of course, would have to be raised appreciably, necessitating effective blade cooling and improved materials, the pressure ratio employed would also be much higher and improved casing and duct design would contribute to improve thermal efficiency. It was hoped that simplicity would not vanish in favour of high efficiency and the authors saw no reason why it should.

No trouble had been experienced in the *Auris,* due to the rise of the h.p. turbine speed on opening the bypass valve, if care was taken to see that there was no output from the alternator when the bypass valve was voluntarily opened. Should the bypass valve be accidentally opened when the normal quantity of fuel was being burnt, the l.p. turbine speed would immediately rise and shut off the fuel before the speed of either the h.p. or l.p. shaft had achieved a dangerous magnitude.

Apart from an overspeed trip operating the fuel valve, which was also operated by failure of lubricating oil pressure, the fuel system was of simple construction and was not connected to a governor.

When operating normally at sea, the governors on the Diesel engines directly controlled the fluctuations of the shaft revolutions and hence the l.p. turbine revolutions. No appreciable change took place in the h.p. turbine shaft speed when the propeller tended to race in a seaway.

No governing difficulties were anticipated with future gas turbine installations as there would probably be a compressor on both the h.p. and l.p. turbine shafts.

The *Auris* turbine had operated for over 2,000 hours on high viscosity fuels. As mentioned in the paper, for part of this time incomplete combustion was purposely produced, but the authors did not believe this to be the solution because of the fouling likely to be encountered in the heat exchanger and exhaust duct. It was believed that much could be gained from improved blade design and that the ultimate solution would be found in the employment of suitable fuel additives.

In reply to Commander Wilson, the authors said that since the paper was written, the h.p. and l.p. turbines, as well as the compressor, had been completely opened up and thoroughly examined. The cause of the l.p. turbine gripping had now been determined and was due to movement of the forward pedestal bearing. The simple modification to be carried out would obviate a recurrence of this trouble.

The turbine had often been restarted before being completely cooled out; as, for example, when one of the three Diesel engines had been desynchronized for a repair lasting an hour or two. Another example occurred when a pilot was picked up, followed by a long harbour passage. Recently the turbine was shut down and the burners relit twelve times in quick succession without the slightest difficulty.

Efforts were now being made to determine the blade clearances under working conditions, as such information was considered desirable.

The combustion chamber refractories had never dictated the time allowed for cooling the turbine. The most exacting condition occurred when the fuel was suddenly shut off at full load when comparatively cool air was blown across them, though even such severe treatment had had no apparent adverse effect.

The normal idling speed of the h.p. turbine/compressor shaft was about 3,800 r.p.m., and an attempt was once made to clean the compressor at this speed. It did not prove satisfactory, as some of the deposits were merely transferred to the discharge end of the component. The routine described in the paper had proved both simple and effective.

Since the turbine had been installed in the ship the flame had not on any occasion gone out of its own accord. A blow-out test has been tried but the fuel would remain ignited even with a high compressor speed and a minimum burner lance setting.

The authors share Commander Wilson's views regarding the unwieldy but necessary heat exchanger. The tubes were purposely made of large diameter because of possible fouling, large diameter tubes being easier to clean. When further experience had been gained and combustion troubles overcome, the tubes of future installations would doubtless be of smaller diameter and the size of the heat exchanger less, but the reduction in space occupied would not be appreciable because exhaust ducts of gas turbines would of necessity always be large if back pressure was to be avoided.

Regarding the points raised by Mr. Lyder Kahrs, the authors stated that from the blade inspections it appeared that the greatest amount of deposit accumulated at the breakaway point of the back face of the stator blades. At higher turbine temperatures the increased corrosion rate appeared to affect the rate of deposition so that the general effect was a reduced rate of deposition. It was anticipated that if a corrosion-resistant material could be found to withstand, say, 800 deg. C., then the deposition rate would be higher than at 650 deg. C.

The recommendation to limit the maximum turbine inlet temperature to 1,200 deg. F. was based on the necessity of acquiring much more running time in order to gain experience of the more simple, practical difficulties before the more complicated problems of high temperature deposition and corrosion masked them. It was known from laboratory work that above this temperature much more difficult corrosion problems might be expected. The authors' views of future developments were given in the replies to Sir Harold Roxbee Cox and Mr. Kilchenmann.

To Messrs. Draper and Bowen the authors expressed their appreciation of the valuable work done by them in the design of the combustion chambers in the *Auris.* Mr. Draper's computation of the running costs of steam turbine and gas turbine installations was interesting but the authors would not venture at this stage of gas turbine development to assess the economics of the latter. There were far too many unknown factors which could be cleared up only by long sea experience. The most that could be said at the present time was that the authors were firmly of the opinion that the adoption of gas turbines for ship propulsion was a progressive step and that the overall efficiency of the next gas turbine-propelled ship, referred to in the paper, would be greater than an equivalent geared steam turbine or Diesel ship.

In reply to Mr. Alcock, the authors would state that they did not consider that the closer pitching, more complicated methods of staying small diameter tubes and the larger number of tubes that would be required in the heat exchanger was very attractive, particularly when a large duct was in any case required. Ease of cleaning was considered to be more important than weight at the present time, and in a marine installation the difficulty of staying long slender tubes to withstand vibration might be a serious problem.

The authors were pleased to have the views of Mr. Lubbock, who did so much for the aero jet turbine, upon combustion chambers. The final answer might be multiple chambers but the authors were of the opinion that from the point of view of thorough mixing of the products of combustion, the smaller the number of chambers the better.

They also felt that unlined combustion chambers would ultimately be adopted but that until further progress had been made the metal casings would require to be protected by refractory material. The two years' experience with refractory-lined combustion chambers in the *Auris* proved that there need be no apprehension in this respect.

Mr. Thompson asked for initial costs of comparative ships engined by steam (presumably turbines), Diesel engines and gas turbines. Such information regarding the first and second, providing the ships had been delivered, was readily available, but when one remembers that even now shipowners never knew what they were going to have to pay for a steam or Diesel-engined ship until after it was completed, the extreme difficulty of giving a price for a ship propelled by a gas turbine would be appreciated.

To give the initial cost of the *Auris* gas turbine would be very misleading, as such a figure would include development charges. This applied also to the next gas turbine ship to be built, but in the case of subsequent ships a fair guess of the costs, and the authors would emphasize that it was only a guess, would be:— steam turbine ship, 100; Diesel engined ship, 93; and a gas turbine ship, 105.

Like all new developments, the machinery arrangement of a gas turbine ship as at present conceived would be simplified and costs of special heat-resisting steels would be reduced as the demand increased, so that it was not unlikely that the initial cost of such a ship would before long compare more favourably with other types.

Captain Atkin was of the opinion that marine engineers would make better progress and be more likely to obtain the desired results if they were guided by aircraft rather than steam turbine developments. Whilst the authors would be the first to admit that much information made available by the aircraft industry could be made use of, it must be remembered that an immense amount of effort had been put into the steam turbine and that steam turbines had been designed to meet sea conditions, which were rather different from conditions in the air.

The authors considered that for satisfactory long and continuous operation in a merchant ship, a gas turbine must be designed to withstand conditions the severity of which were only met with at sea. It was now quite normal for a tanker, such as the *Auris,* to be away from the United Kingdom for nine to twelve months. It had been found that such items as stainless steel bolts and nuts, or bolts of non-Whitworth thread, and the repairs of nimonic and special alloys all became major difficulties in any but the largest ports. It was thus clear that small, more complex or highly rated parts requiring frequent renewal were more undesirable than a robust heavy unit with a long life.

Reference had already been made in replies to previous speakers to the good results obtained with the refractory lined combustion chambers in the *Auris.* Whilst not ideal, the authors saw no serious objection to refractory linings. If water entered the combustion chambers with the fuel, serious trouble would result, of course, but surely the well-known simple and effective methods of getting rid of water would obviate this. Had this not been so, the Diesel engine would not have become so popular.

Replying to Mr. Bulman, it was not the practice to give the engine room staff of the *Auris* any special training before taking over, nor were they selected because of any special knowledge they might possess. During the first round voyage a dual watchkeeping system with personnel already acquainted with the turbine was instigated, but since that time it had been found that the average engineer could accommodate himself to gas turbines as quickly as he could to steam turbines or Diesel engines.

The loss of h.p. turbine efficiency between 23.6.52 and 4.7.52, shown in Table I, was estimated to be 1·5 per cent and not 7 per cent as suggested by Mr. Bulman. It had been pointed out in the paper that due to stratification the h.p. turbine inlet temperature recorded was unreliable and it was, therefore, not used for estimating performance results. The normal method was to use the compressor temperature rise in conjunction with a turbine/compressor relationship.

Since the paper was written, several tests had been carried out, with both incomplete combustion and the use of additives. The results strengthened the authors' belief that there was no reason why future gas turbines should not operate efficiently and continuously on the longest voyages and under the most adverse conditions.

As stated in the paper, the fuel economy of the *Auris* gas turbine was not considered during the design stage, but even so it did not fall far short of a steam turbine of equal rated power. In the case of the 8,300 b.h.p. gas turbine installation now being constructed for the same owners, the fuel economy would be as good as a great many modern steam turbine installations.

The authors were indebted to Mr. Colvill for his contribution and agreed with his statement that, although indirect drive had existed for over twenty years, it had not become popular, the reasons being higher initial cost and slightly increased fuel consumption for a given power developed due to transmission losses.

Hitherto these had been the chief factors determining the type of propelling machinery, the cost, and particularly the time to put a ship through periodical refit being of lesser importance. Conditions in regard to this item of operating costs had, however, changed from the time when the authors saw a 74-ton crankshaft changed in eight days. Such a job would take nearer eight weeks at the present time and the cost would be increased almost proportionately. Moreover, the daily loss to the owner of this particular ship was £250, while today the loss, due to greater capital cost, insurance, etc., would be in the region of £800 per day.

If, as recommended by the authors, the power plant was divided into small units—say, 1,000 b.h.p.—such long off-hire periods would be avoided. It was realized, of course, that such big jobs as changing crankshafts did not have to be undertaken very often, but the proposed scheme would give the ships' staff a better opportunity to keep the machinery up to the required standard and, in consequence, reduce very substantially the cost and time to put a ship through periodical refit. A further advantage would be as stated in the paper, to enable part of the propelling machinery to be employed for cargo discharge.

The engine room of the *Auris* was fitted with the usual foam extinguishers and two carbon tetrachloride extinguishers. Most of the lubricating oil fires which occurred in the centre pedestal pocket were very successfully extinguished by a few squirts of carbon tetrachloride. On one occasion, three 2-gallon foam extinguishers were emptied into the region of the centre pedestal.

During the last two years the turbine was not specially opened up on any occasion to perform the manual scraping operation. The turbine was opened expressly for examination and while open the opportunity was taken to manually clean it.

A high frequency vibrator for removing deposits had not been tried since cooling down had so far proved effective.

The turbine normally operated on an h.p. turbine inlet limiting temperature. If this was kept constant, the gradual loss was shown as a decrease in output.

Mr. Holmes Fletcher's description of the Rolls-Royce R.M.60 gas turbine made interesting reading and the designers were to be congratulated upon getting the weight per unit power developed to such a low figure, while the starting and manœuvring qualities were indeed commendable but not really necessary for merchant ships.

The scantlings of the R.M.60 must be very light and certain vital parts, such as heat exchanger tubes, extremely thin, and one wondered what life such parts would have in a merchant ship which must operate on whatever fuel was available in any part of the world and after twenty to thirty days' continuous operation occasionally encountered a heavy sea that made the ship do everything but turn over.

When it was decided to make the *Auris* gas turbine suitable for ahead running only, there was very little information about combustion chamber design available, and no experience of running a gas turbo alternator in parallel with a comparatively slow speed Diesel alternator. To manœuvre with the turbine would have necessitated a double unit alternator, more elaborate switching equipment and, at that time, an untried complicated fuel system. Simplicity was of paramount importance.

The new 8,300 h.p. gas turbine tanker would manœuvre entirely on either or both of the gas turbines. It was expected that this ship would manœuvre as well as or even better than a sister ship now at sea which was propelled by steam turbo-electric machinery. The authors believed that merchant ships' manœuvring requirements were as arduous as any met with in naval ships. This was perhaps even more true of single screw tankers which must often berth in ports abroad without the aid of tugs. To give some indication of the telegraph demands, the following figures had been taken from a recent movements book of the *Auris.*

In one 8½-hour period, 184 telegraph orders were given, many being ahead to astern movements. During one 74-minute period, 38 engine movements were executed and these were either full ahead, full astern or stop.

The efficiency figure quoted for the new ship did not include transmission losses. The transmission efficiency was expected to be about 91·5 per cent. Some use would be made of waste heat and it was anticipated that the whole installation would compete satisfactorily with comparable steamships.

It was expected that there would be an adequate supply of boiler oil at most of the bunkering ports of the world for many years to come. To be satisfactory, a gas turbine ship must be capable of burning all normal grades of liquid fuel.

The loss of output due to an increase in ambient temperature was undesirable and it was intended that future designs would be based on tropical temperatures with suitable margins for maximum power.

In reply to Mr. Jacobs, the authors would state that the normal operating procedure was to start the turbine shortly before "stand-by" on leaving a port and allow it to idle until "full away" was given. This procedure enabled adequate warming through to be carried out and the turbine was ready for increasing load at the most opportune moment. When arriving at a port the turbine was shut down when the pilot was taken on board unless there was a long pilotage without astern movements. Should a sudden engine movement be required, the turbine fuel was cut off and a re-light carried out rather than have the turbine rotors stopped and a normal start made.

The design of changeover valves for high temperatures and large mass flow would be difficult and the complicated control gear would be undesirable.

Heating the inlet air to the compressor would be most undesirable due to the extra work required for compression. A more profitable scheme would be a steam jet refrigerator operating on steam from exhaust boilers, but the units would be large and the capital cost excessive.

The authors agreed with Mr. Pope that the marine gas turbine should not be derated due to part of one component. Whereas it had been suggested by Mr. Pope that three years should be the expected life of the high temperature end of the h.p. turbine, the authors repeated their view given in the paper that 20,000 hours or four years at 5,000 hours per annum was a better and attainable target.

The existing design of turbine in the *Auris* had a number of features dictated by the limited space made available by the removal of one Diesel engine. It was considered that bypass valves were not necessary, a single vertical combustion chamber was more desirable and, of course, one unit above the other would not be repeated where there was sufficient athwartships space.

The authors were pleased to note that Mr. Smith held similar views to theirs regarding the transmission of power from the power producers to the propeller. In the contemplated 18,000-ton gas turbine-propelled tanker referred to in the paper, the question of mechanical drive was seriously considered but it was finally decided that manœuvring would entail difficulties and that some further development work was necessary before the safety of a ship would be entrusted to this form of drive.

INSTITUTE ACTIVITIES

Minutes of Extraordinary General Meeting held on Tuesday, 14th July 1953

An Extraordinary General Meeting of the Institute was held at the Institute premises on Tuesday, 14th July 1953, at 5.30 p.m., for the purpose of considering and, if deemed desirable, passing a Special Resolution.

The President, Sir Gilmour Jenkins, K.C.B., K.B.E., M.C., was in the Chair.

The PRESIDENT explained that the purpose of the meeting was to consider the following Special Resolution, which he formally moved:—

> "That subject to the provisions of Article 20 of the Royal Charter of The Institute dated 19th April 1933, the By-Laws of The Institute shall be amended as indicated hereunder:—
>
> By-Law 47.—Delete the present wording of the first sentence only and substitute new wording as follows:—
>
> 47. Any ballot paper which, when returned to the Secretary, contains the names of more than one President, one Honorary Treasurer, or more or less names of Members and Associate Members from amongst those nominated as Vice-Presidents or as ordinary Members and Associate Members of Council than there are vacancies to be filled, shall be void . . ."

MR. E. R. HALL (Member) said that he had expressed his views on the subject at the previous Annual General Meeting, but that he did not elaborate on them a great deal at that meeting because he felt a little guilty at introducing extra business, and thought that members might possibly resent being kept later than they had anticipated. However, Mr. Wheadon had suggested that more notice should have been given of the business which was raised.

Perhaps more notice could have been given, but he liked to be sure of his facts. Many years ago he had attended a committee meeting at the Institute when a complaint was tabled that at a social function held in the lecture hall an infringement of the By-Laws had occurred. Having an enquiring turn of mind, he had asked for the By-Laws to be produced, and it was found with some surprise that the By-Laws at that time did not in fact prohibit the alleged "infringement".

When he received the ballot paper he thought that there was something unusual about it, but filled it in and posted it. As opportunity presented itself, he looked at the By-Laws and found that the omission of the proposers' and seconders' names was quite in order, but the question of not less than eight votes and not more than eight votes was not clear. The only way is which he could check this was to get a copy ballot paper, and after the close of the ballot he asked for one. On receiving it he was able to verify that an irregularity had taken place and gave notice that the matter would be raised at the meeting.

Dealing with the Special Resolution, he pointed out that the meeting was being held on the 14th July, and on that date in 1789 the French peasants rose up, and fought for liberty, and a hundred years later, in 1889, the original Articles of Association of the Institute were founded, and certain liberties were given to the members in their manner of voting. Those liberties had obtained up to the present day with the exception of the last ballot when they were somewhat irregularly taken from the members. He had no complaint about the taking away of liberties if it were done constitutionally by agreement of the members at a general meeting, but in looking into the matter since then he had found that there were a number of small irregularities which, although perhaps unimportant singly, in the aggregate seemed to show that something was not quite happy. In order that he might bring those to the notice of the meeting, he desired to amplify the vote of confidence which, he was glad to say, had been carried unanimously at the previous general meeting. With the President's permission he desired to amplify that vote of confidence before the discussion proceeded and disclosed other facts which might bear on the regularity or otherwise of the ballot.

The PRESIDENT pointed out that the meeting had been convened for one purpose only, namely, to discuss the Special Resolution. It was difficult to see how a vote of confidence came into the deliberations.

MR. HALL said in that case he could only proceed and suggest that the ballot might have been called irregular on more counts than the one to which he had already referred concerning the number of votes to be used. In the first place the ballot paper bore a note that it should be returned by the 9th March, whereas the general meeting was held on the 24th March. According to the By-Laws the ballot was open until four clear days before the meeting. That was one of the reasons why he felt it was necessary to regularize the previous ballot by a vote of confidence at the present stage.

To pursue the matter of history, in 1939 a motion was placed before the meeting to increase subscriptions. He had the pleasure of supporting that motion, but he pointed out to the meeting that it was a motion—as was the one under discussion—which affected every member of the Institute with voting powers, and he suggested, as he suggested in the present instance, that possibly those in London, who had better opportunities of knowing potential candidates than members in the provinces and at sea, were not perhaps in a position to give the final word on the motion. As at the general meeting in 1939, he suggested that possibly the best course would be to discuss the motion, accept it or amend it, and then put it to the membership by means of a poll. He had in mind a postal vote so that the members, as a whole, might decide on what was to happen about the change in the By-Law.

The view might be taken that a postal vote would not bring much response. He could not say whether the President would permit the disclosure of the number of ballot papers which came in for the annual general meeting, but in the postal vote held in 1939 some 880 votes were recorded out of 3,500 members entitled to vote—about 25 per cent. He hazarded the guess that the return of ballot papers from the present corporate membership of 5,000 did not approach anything like 25 per cent. Therefore, he suggested that the membership in the provinces and at sea was quite interested in such motions which closely affected them, and in his submission the acceptance or otherwise of the Special Resolution should, after it had been debated and amended as thought fit by the meeting, be submitted to the members by poll. He therefore proposed in the first instance that the eventual decision on the Special Resolution be taken by poll.

The PRESIDENT asked Mr. Hall whether his proposition was that a decision should not be come to by the meeting on the Special Resolution but that it should be referred to a poll of the whole membership.

MR. HALL: Yes.

The PRESIDENT said that it was a question of whether it was competent to do that under the By-Laws. (The President conferred with the Secretary.)

He said that he understood that the matter had been referred to the Institute's legal adviser and the advice given was that if a poll were demanded, and if the decision were taken that there should be a poll, it would, in those circumstances, be a poll of the members present at the meeting.

MR. HALL said he apologized for being in error in that connexion. He had read the By-Laws to mean that the poll should be taken in the manner and as directed by the Chairman, and in the previous instance which he quoted—the general meeting of 1939—the Chairman agreed that the decision should be taken by a postal vote.

The PRESIDENT replied that in accordance with the By-Laws, a decision had to be reached at the meeting.

MR. HALL said that it was necessary to bear in mind that those members in London were in a much better position to know and to judge candidates than were their friends and colleagues in the provinces and at sea. Members in the provinces and at sea who could not possibly attend the meeting could not vote by proxy, they were apparently unable to vote by post, and it would seem that those in London who could attend had the whole matter in their hands. He suggested that serious consideration might be given to that aspect.

It was a little difficult for a London member to detach himself entirely and to imagine that he was away from London altogether and had possibly never set eyes on the Institute's headquarters, but that was the position of many members who were faced with a list of names containing perhaps only one or two of those whom they knew. If the Special Resolution were carried—and he trusted that it would not be—it would mean that the ballot would become something of a lottery, and in his view that did not make for a good election.

Another point which he had noticed in the course of his researches into the matter was that it would appear that the counting of the votes at the last ballot was not strictly in order and, similarly, the proposals for the counting of the votes at the next meeting appeared to be not strictly in order. The By-Laws provided for two scrutineers, but four were elected to serve at the previous general meeting having, he suggested, been somewhat irregularly elected. The same position obtained at present, and in his view it should be cleared up before the next general meeting. It would become apparent what he meant when he said that there were a number of things which seemed to be a little off the rails.

The Special Resolution was so worded that it affected only the number of votes which could be used. It did not appear to envisage that the new form of ballot paper would be retained. It might be useful if some confirmation could be given that the new form of ballot paper would continue to be used.

The PRESIDENT replied that the question of the ballot paper had not yet been considered.

MR. HALL suggested that the new form of ballot paper was much more workmanlike than the old form. It must be much easier for the scrutineers to check. On the former ballot paper if there were two vacancies a member crossed out two names. On the new ballot paper if there were two vacancies the voter simply inserted X's. The By-Law was framed at present so that if more names were standing on the ballot paper than there were vacancies, the paper became invalid. He suggested that on the new ballot paper all the names were still standing and he therefore proposed by way of amendment: —

"That the new wording shall read as follows: —

47. Any ballot paper which, when returned to the Secretary, contains the names of more than one President, one Honorary Treasurer, or more names of Members and Associate Members from amongst those nominated as Vice-Presidents or more votes than there are vacancies to be filled by ordinary Members or Associate Members of Council respectively, shall be void . . ."

The PRESIDENT said that the effect of Mr. Hall's amendment was to delete from the Resolution the words "or less". It would make it possible to vote for fewer people but not for more. It was almost a direct negative, therefore, of the Special Resolution.

MR. W. TWIZELL (Member) said he had attended the meeting in order to be enlightened on the reasons for the change of the By-Law, and he desired to know what was the matter with the present By-Law.

The PRESIDENT replied that the meeting would no doubt hear about that.

MR. H. J. WHEADON (Vice-President) said that Mr. Hall had spoken about revolutions and other things when it would appear that he really meant red herrings. Mr. Hall appeared to throw some doubt on the honesty of the Council in dealing with voting and had not dealt with the fundamentals of the issue. Mr. Hall might well have developed his main argument a little more rather than deal with such fine and somewhat irrelevant points, some of which would seem to be a little distasteful. The Members of Council spent a great deal of time year in and year out working on behalf of the Institute, and the suggestion which he seemed to detect in Mr. Hall's statement (if he were wrong he apologized) that the Council were trying to put over something a "bit quick" was, so far as he was concerned, somewhat objectionable.

The proposed change in the method of voting was not new to members, because of his own knowledge there were a large number of members who had always voted in the manner proposed. It was the minority who had been voting in the way which Mr. Hall was advocating which had resulted in chances of certain individuals' election in the past being loaded.

Mr. Hall made the point that some members in the provinces and at sea did not know the candidates for election as well as the London members knew them. The Council considered that question some years ago and decided to insert alongside each name a history of the candidate, including such matters as his work for the Institute and so forth, in order to guide members when voting. In any event, it was only necessary to vote for eight candidates out of sixteen, and surely there must be out of sixteen candidates eight who were well known throughout the Merchant Marine.

The issue was really so simple that it did not call for a great deal of discussion. He felt confident that Mr. Hall would have very few supporters for his proposition.

MR. HALL assured Mr. Wheadon that he appreciated the work which was done by the Council and the committees of the Institute perhaps more than most. He did not suggest for one moment that because there had been a technical slip in the election of scrutineers that there was anything basically unsound about it or any ulterior motive.

What he did suggest was that perhaps it might have been better if, before action were taken, somebody had realized that the By-Laws were affected and that the By-Laws should be put in order before decisions were put into force.

Mr. Wheadon said that it was easy to pick eight candidates out of sixteen. Mr. Hall pointed out that he did not support block voting as such and that he had never sent in anything less than a full ballot paper because he desired to use his votes and felt that it was in the right spirit. Nevertheless, Mr. Wheadon maintained that it had happened that a minority pledged their support for one candidate and were still prepared to do so. He agreed with Mr. Wheadon that it hardly seemed fair if that was confined to, say, one particular member. If, on the other hand, it were publicly known that it was permissible for all members to have recourse to that method if they chose to sink to it, the effect would be nullified. He could not help thinking that in tying the matter up in the manner proposed by the Special Resolution, the Institute were taking a retrograde step, and it should be left to the members to vote as their consciences guided them.

MR. C. P. HARRISON (Member of Council) said that in his view the words "more or less" should be included.

MR. A. ROBERTSON (Honorary Treasurer) pointed out that the question before the meeting was simply one of principle, and the reason for its introduction was that outlined by Mr. Wheadon, namely, to prevent block voting. As matters stood it was possible, by means of subterfuge, for someone to secure election to the Council, and that was the only reason for the proposed alteration.

MR. S. G. CRACKNELL (Member) asked whether there had been any occasion on which block voting had been proved to have taken place.

The PRESIDENT replied that there had been cases, so he was advised, in which the full number of votes had not appeared on the voting paper. Nobody would attempt to answer whether people had deliberately engaged in block voting. That was something quite different.

MR. TWIZELL said that, while he had no personal objection to the proposed change in the By-Law, he considered it placed the sea-going members in a difficult position. He remembered his own years at sea and the difficulty he was in on receiving the ballot paper, generally in some foreign port, and was faced with the task of voting, when only two or three of the names on the paper meant anything to him. He asked if there were any concrete evidence that the By-Law at present in force produced any unfair result.

The PRESIDENT said that no one was suggesting that there had been any attempt in the Institute to use the ballot in an improper way by block voting in order to get certain people elected. Even if it were suspected, nobody could prove it. It had been known to happen in other organizations and it was in order to safeguard the position of the Institute and to ensure that no such thing could happen that the Council proposed the change.

MR. TWIZELL pointed out that it was difficult to vote for someone about whom nothing was known and he thought it unfair to place members in the position of having to vote for a number of people they knew nothing about or be disqualified from voting at all.

The PRESIDENT, in reply, said that was the reason for inserting particulars of candidates on the voting paper.

MR. ROBERTSON explained, for the information of the members present, that the Resolution had been sent to every corporate member, and it would be of interest to know whether any objection had been raised in writing.

The PRESIDENT said that the answer was no.

MR. WHEADON said that before the last election he was approached by two people who were backing a certain person, and was asked to give him one vote. That was one of the reasons for his decision to bring the matter before the Council.

MR. A. D. TIMPSON (Member) suggested that a brief history might be given in the case of each candidate—not his present position—but a brief history along the lines of the procedure adopted in the past.

The PRESIDENT ruled that the suggestion was strictly out of order at the meeting but he felt sure that the Council would consider it. At the present time the candidate's present position was given on one side of the paper and his service to the Institute on the other, but there was no history of his career outside the Institute. Consideration would be given to that suggestion.

The sole object of the present meeting was to accept or reject the Special Resolution which had been circulated to all members.

The Resolution was put to the meeting and carried, with one dissentient.

The PRESIDENT said that the drafting of the Resolution and consideration of it had drawn attention to the fact that the By-Laws were a little obscure in places, and some were out of date and required revision. The Council proposed, as a result of their consideration, to put the matter in hand and to clear up the By-Laws.

MR. HALL said he applauded the suggestion that the By-Laws should be tidied up.

The meeting then terminated.

Minutes of Proceedings of the Ordinary Meeting held at the Institute on Tuesday, 13th October 1953.

An Ordinary Meeting was held at the Institute on Tuesday, 13th October 1953, at 5.30 p.m., when a paper entitled "Operation of a Marine Gas Turbine under Sea Conditions", by John Lamb, O.B.E. (Member) and R. M. Duggan, B.A. (Associate Member), was presented and discussed. Mr. Stewart Hogg (Chairman of Council) was in the Chair. Eleven speakers took part in the discussion and 230 members and visitors were present.

A vote of thanks to the authors, proposed by the Chairman, was accorded with enthusiasm. The meeting ended at 8.20 p.m.

Local Sections

Merseyside and North Western

At the second Ordinary Meeting of the session, held at the Temple, Dale Street, Liverpool, on Monday, 2nd November 1953, at 6.30 p.m., the Chairman, Mr. G. Pickering, opening the proceedings, expressed his pleasure at seeing a number of visitors present. Members, visitors and students numbered 210. He then introduced Mr. John Lamb, O.B.E., M.I.Mar.E., and Mr. R. M. Duggan, B.A.(Hons.), A.M.I.Mar.E., and asked them to read their paper entitled "The Operation of a Marine Gas Turbine under Sea Conditions". (Repeat of the paper read before the Institute on the 13th October 1953.)

Introducing the subject, Mr. Lamb explained the reasoning that had led him to conclude that the use of a gas turbine for main propulsion was economically sound. He then set out the principal objects of the *Auris* experiment, which were to acquire operating experience and develop the fuel burning equipment.

Mr. Duggan then read extracts from the paper, illustrating his remarks with a number of slides.

Between them, Mr. Lamb and Mr. Duggan dealt with a long discussion. Contributions naturally fell into two main categories—those dealing with the future development and application of the gas turbine, and those concerned with design and operational problems. Mr. Duggan's answers to the latter were very full and frank.

Proposing a vote of thanks, Mr. A. G. Arnold (Member) complimented the authors on their very fine paper and on the skill and enterprise that had brought the subject of it into being. He hoped, however, that they would endeavour to avoid so far as possible the use of special materials, as he could foresee difficulties with replacements. The vote of thanks was passed with acclamation.

North East Coast

On Thursday, 19th November 1953, Dr. E. J. Boorman presented a lecture on "Petroleum Refining" at the Technical College, Sunderland. There were forty members and students present.

The lecturer said that crude petroleum was useless as it came from the ground and the group of processes which were used to convert it into motor spirit, kerosene, fuel oils, lubricants, asphalt, synthetic chemicals, etc., was called "refining". The numerous hydrocarbon molecules in oil were first separated into groups corresponding to the final products by distillation through the fractionating tower of a pipe still. This repeated intermingling of vapours and condensed liquids resulted in the production of the necessary fractions which were afterwards given a final purification before being pumped to storage.

As the demand for motor spirit exceeded the supply from that naturally present in crude oil, the less volatile fractions were converted into more and better motor spirit by high temperature treatment called cracking. The most modern fluid catalytic cracking processes now produced a large proportion of today's petrol.

Still heavier fractions were treated, purified and blended to produce the large range of modern and specialized lubricating oils which industry required. Additional products like grease, paraffin wax, and bitumen were also derived from oil. By-product gases were converted into chemicals, synthetic rubber, plastics, fibres and numerous other materials. The continued development of all these products was maintained by extensive research.

Scottish

At the general meeting held on 25th November 1953, Mr. T. A. Crowe, M.Sc. (Chairman of the Section) presided and 135 members and visitors were present.

The Institute prize awarded to the best first year student taking the Ordinary National Diploma Course under the new Apprenticeship Scheme was won by H. A. McD. Cowan (Student), of Stow College School of Engineering, Glasgow. The presentation of the prize was made at this meeting by Mr. Crowe and greeted with hearty applause.

A paper on "The Operation of a Marine Gas Turbine under Sea Conditions" was then read by the authors, Mr. John Lamb, O.B.E. (Member) and Mr. R. M. Duggan, B.A.(Hons.) (Associate Member). Mr. Lamb introduced the subject by briefly outlining the present-day position of the marine gas turbine and Mr. Duggan continued, reading the greater part of the paper.

In the discussion which followed, nine speakers took part, and on the proposal of Mr. D. A. Low, a hearty vote of thanks was accorded.

Sydney

The Annual Dinner of the Sydney Section was held at the Wentworth Hotel, Sydney, on Wednesday, 18th November 1953. The attendance was seventy-eight, comprising forty members and thirty-eight guests. The official guests included Vice-Admiral(E) Sir Denis Maxwell, K.C.B., C.B.E., recently retired from the appointment of Engineer-in-Chief of the Fleet; Rear-Admiral(E) C. C. Clark, O.B.E., D.S.C. (Third Naval Member and Chief of Construction of the Naval Board); Captain(E) K. McK. Urquhart (engineer manager, Garden Island); Messrs. John R. Dingle (manager for New South Wales of the Shell Company of Australia, Ltd.); V. J. F. Brain (Chairman, N.S.W. Electricity Commission); W. H. H. Gibson (President of the Institution of Engineers, Australia); A. Denning (Director of Technical Education, New South Wales); and W. A. Harrington, who presented a paper on "Piston Rings" to the Section during the year.

The Local Vice-President, Mr. H. A. Garnett, presided at the Dinner.

After the Loyal Toast, the toast of The Institute of Marine Engineers was proposed by Mr. John Dingle, who was trained and served as a marine engineer in his younger days. Mr. H. W. Lees (Member) responded on behalf of the Sydney Section.

The toast of "Our Guests" was proposed by Mr. W. H. Gregory and replied to by Vice-Admiral(E) Sir Denis Maxwell. Sir Denis gave a most interesting address, which was greatly appreciated by all those who were present.

The Dinner was again a most successful function and the change of location to the Wentworth Hotel was much appreciated as more space was available and the arrangements were generally superior.

Junior Section

South East London

A lecture on "Marine Diesel Engines" was given by Mr. A. G. Arnold (Member) at the South East London Technical

College, on Thursday, 5th November 1953, at 2.0 p.m.

The meeting was well attended, the Principal of the College, Mr. H. A. Warren, M.Sc.(Eng.), the head of the mechanical engineering department, Mr. H. McQueen, B.Sc. (Eng.), several members of the teaching staff, and over one hundred students being present.

As Chairman, Mr. H. R. S. G. Lake, B.Sc.(Eng.), secretary of the college Mechanical Engineering and Building Society, introduced Mr. Arnold to the meeting.

Close attention to the lecture was shown by the students and members of the staff, and at the close of the lecture the number and nature of the questions put to, and answered by, Mr. Arnold, proved that interest, both in Diesel engines and marine engineering, had been stimulated.

The lecture was well illustrated by slides, and by a film made by Mr. D. W. E. Kyle (Associate), who accompanied Mr. Arnold.

Com'r(E) F. Roberts, O.B.E., D.S.C., R.N.(ret.) (Member), representing the Council of the Institute, after referring briefly to the advantages of membership of the Institute, proposed a vote of thanks to Mr. Arnold and Mr. Kyle, which was accorded by acclamation.

Student Lecture

85, The Minories

Approximately 110 students attended a Student Lecture at the Institute on Monday, 2nd November 1953, when Mr. George Yellowley of the North Eastern Marine Engineering Co., Ltd., lectured on "The Steam Reciprocating Engine".

His talk, which was illustrated by an impressive collection of slides, both pictorial and diagrammatic, dealt with the following types of marine main propulsion plants:—

1. Triple expansion steam engine (with descriptions of piston valves, balanced slide valves and poppet valves).
2. Fredriksstadt steam motor.
3. Triple expansion steam engine with Bauer Wach exhaust turbine.
4. The N.E.M. reheat steam engine.

Of particular interest were the admirable diagrammatic plans illustrating steam and water flow through steam reciprocating installations.

Afterwards, the author replied to numerous questions and it was hoped that he would give a further lecture on this subject, when he could devote more time to the individual installations mentioned in his paper.

Mr. R. G. Brett (Associate Member), who took the Chair, proposed a vote of thanks to the author, which was accorded by acclamation.

Membership Elections

Elected 11th November 1953

MEMBERS

William Robert Adam
Herbert Farquhar Atkins, Capt.(E), R.N.
Alexander William Matthew Barkway
Archibald Benjamin Boalch
William Wood Weir Burgess
Oliver Charters
Joseph Charles Copeland
Frederic John Corney, Com'r(E), R.N.
George Dempster
Robert Duncan Fairley
George Harry Glanville, Lt. Com'r(E), R.N.
James Stewart Hepburn
George William Hill
John McCabe
Angus MacLachlan
George McNamara
Karl Mahringer
Roger Edward Morris
John Ritchie
James Gordon Ruffell
Johan Gerard Schoo
John Campbell Shanks
Sydney Albert Sutton

ASSOCIATE MEMBERS

Colin Herbert Edward Brewster
Colin Ralph Brown
John Eastwell Burton, B.Sc.
George Nicholson
Arthur Walter Wheeler

COMPANION

Richard George Meredith Street

ASSOCIATES

Joseph William Aspinall
Phiroze Nadershaw Bhathena
Thomas Henry Bradshaw
Kenneth Walter Campbell
Alfred John William Clegg, Lieut.(E), D.S.C., R.N.
James Arthur Cockill
David Athol Coull
Gerald Farnsworth
Mukund G. Kale
Michael Ian Lees
Roy McBurney
John Edward Teasdale Mason
Leonard Mills
John Reginald Mitchell, E.R.A., R.N.
William Kenneth Pitt-Jones
Ronald Wallace Rosen
Arthur Alwyn Rouse
Philip Willmore Sands
John Sinclair
Milton Clifford Taylor
Roy Dennis Tomlinson

GRADUATES

Harry Allison Bell, Lieut.(E), R.C.N.
Basil Malcolm Theodore Clark
Michael John Neeves, Lieut.(E), R.N.

STUDENTS

Michael James Chadderton
Anthreas Nicholas Charcharos
Bernard Robert William French
John Vivian Highton
John Ronald Moore
Derek George Orchard
Kenneth Arthur Peacock
James Kenneth Rankin
Roger Ernest Shields
Philip Richard White

PROBATIONER STUDENTS

Kenneth Millson Brown
William Campbell
George William Clatworthy
Francis William Cockburn
Frederick Peter Cockerell
Roy David Coultas
Colin Cummins
J. Michael Evans
Michael John Ford
Keith Gander
Frank John Gordon
John Harrison
John Brian Hawkins
Richard Tumbridge Haddon Hayton
Michael Reginald Holderness
John Edwin Charles Howe
John Trevor Hughes
Keith Huntley

James Michael Johnston
David Michael Jones
Peter John Kirkland
John Peverley Lamb
William John Verney Ley
Anthony James Lodge
Neville Longstaffe
Barry Charles Lovelock
Edward Joseph McDonald
Derek Charles May
Christopher Roland Alexander Meyer
Derek Patrick O'Leary
John Stuart Oram
Brian Frederick Palmer
Ian Charles Palmer
Peter John Pope
R. D. Preece
Kenneth Roberts
Terence Charles Roomes
Patrick Andrew Sparrow
Robert Graham Thomson
Charles Alan Timms
Ian Warden
Thomas Morton Cairns Watt
Richard Wells
Alan Stewart Whitaker

TRANSFER FROM ASSOCIATE TO MEMBER
John Richard Gale Braddyll, B.Sc.
Thomas Henry Carter
Alexander Hunter
Thomas Wilson Morgan
Roy Edwin Percy Norman
Norman William Robinson
William Rouse
Thomas Stabler Sopp

TRANSFER FROM ASSOCIATE TO ASSOCIATE MEMBER
Leslie Alan Lee
Peter William Yarwood

TRANSFER FROM GRADUATE TO ASSOCIATE MEMBER
Peter Robert Allen

TRANSFER FROM STUDENT TO ASSOCIATE MEMBER
Peter Grimley Evans, Lt. Com'r(E), R.N.
Neil Kirkwood, Lieut.(E), R.N.

TRANSFER FROM STUDENT TO ASSOCIATE
Peter Richard McCleave

Elected 7th December 1953

MEMBERS
John Emmerson Blakey
Frederick Gordon Bull
Maurice Ammanuel Burjony
John Alexander Donald Campbell
John Forcer Crawford
Noel Fearn Daley
James Duff
John Gilliland
Malcolm Johnston
Douglas James Cameron McFadzean
Neil McGilvray
Thomas McIntosh Murdoch
Reginald Henry George Neal
William Henry Ray, Lt. Com'r(E), D.S.C., D.S.M., R.N.
Charles Simpson
Thomas Henley Smith
Sidney Stuart Spence
Joseph Michael Trindade

ASSOCIATE MEMBERS
Peter Louis Antonissen
Angus Campbell Bean
John Clear Harrison, Lieut.(E), B.Eng., R.N.Z.N.
Jack Norman Jonas
Harold Geoffrey Spanner

ASSOCIATES
Odi Nwa Akpa
John Anthony Barton
Norman Edward Bristow
Kenneth Brown
James McGrail Cochrane
John E. I. Deighan
Basil Charles Dodge
William Francis Dowie
Peter Charles Farnham
Michael Norman Ferris
John Glen Gay
Joh. Chr. Gysbers
Leslie Horton
James William Ingle
Austin Jemmett
Guy Shillito Jessop
Eric Levy
Stanley Thomas Long
Herbert McCaig
A. K. Murthy, Lieut.(E), B.E.M., I.N.
Richard Joseph Nelson
Derrick Hillier Palman
Derek Raymond Perkins
John Porteous
John Robert Richardson
William Naismith Robertson
Joseph Scicluna
John Alexander Smith
Abram Spee
James Thornton
Thomas Allan Watt
Thomas Joseph Whittaker

GRADUATES
Alexander Amos Jack Couchman
Frederick Philip Russell

STUDENTS
Laurence Henry Barnes
Ian Bennett
Peter Michael Wilson Cook
John Graham Curzons
Robert Henry Dickens
Brian Michael Egan
Ronald Antony Allcroft Gibbons
David John Kerr-Cross
Paul Grafton Martin
William Murray McKie
George Ralph Anthony Metcalfe
Peter Alexander Milne
Brian Alfred Morrison
Raymond Edward Smith
Cameron Holdsworth Parker
James Keith Wagner

PROBATIONER STUDENTS
Gerald Sykes Benson
Brian Edward Bowes
Derek Burton
Alan Martin Carabine
Barry John Clarkson
Stanley Cotton
Kenneth Dover
Clifford Thomas Evans
Malcolm Henry Graham Fidler
John Michael Frogley
Paul Adlard Gosling
Alan Thomas Hart
Donald John Hindley
Frank Eastwood Jackson

Frank Jones
Leslie Charles King
Edward Nicholas Knaggs
Paul David Kyle
Harry Lane
Dennis Lee
Walter George Vernon Lugg
Geoffrey Frank Mills
Gareth Boycott Oddy
Arnold Holt Parkinson
Brian Albert Payne
Lionel Richard Pryor
Paul Frederick Spires
Fergus Toman
Louis Stanley Voigt
Michael Bernard Walker
Peter Michael Walker
Joseph Marshall Wilson
Peter Wilson

TRANSFER FROM ASSOCIATE MEMBER TO MEMBER
Gilbert Thornton Smith

TRANSFER FROM ASSOCIATE TO MEMBER
Allen Michael James Cumming, Lt. Com'r(E), R.N.
John Edge
Hendrik Johan Hille
Raymond William Knapp

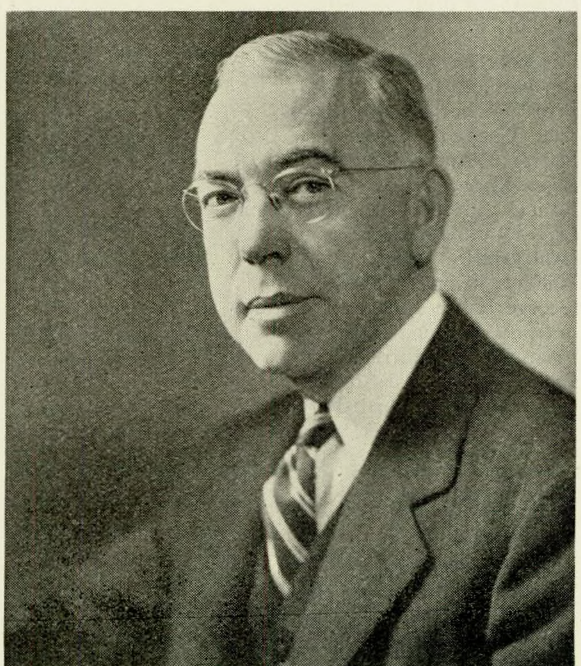
TRANSFER FROM ASSOCIATE TO ASSOCIATE MEMBER
Henry Rogerson Simmonds, Lieut.(E), M.B.E., R.N.Z.N.

TRANSFER FROM PROBATIONER STUDENT TO STUDENT
Eric Mitchell
David Theobald

OBITUARY

JAMES H. KING (Member 6908), of Scarsdale, New York, vice-president and director of the Babcock and Wilcox Company of New York, died at the New Rochelle Hospital, New Rochelle, New York, on 14th November 1953. He was sixty-one years old.

Mr. King was born in New Haven, Connecticut, attended



public schools in New York, and graduated from Yale University in 1913. He joined the Babcock and Wilcox Company in 1914 as a student engineer and was assigned to the marine department in 1917.

He rose to be assistant manager of the marine department in 1928 and was appointed manager of the department in 1931. He was elected a vice-president of the company in 1945 and was named head of the boiler division in January 1952. He was elected a director of the company in April 1953. He also served as a director of the Diamond Power Specialty Corporation of Lancaster, Ohio, and the Hooper Holmes Bureau, Inc., of New York.

Mr. King was the author of various papers on marine boilers and marine propulsion machinery. He was a member of a number of technical societies including the Society of Naval Architects and Marine Engineers, in which he served as president in 1951 and 1952; the North East Coast Institution of Engineers and Shipbuilders, the American Society of Naval Engineers, the Propeller Club of the United States, the American Bureau of Shipping, the Newcomen Society, and the Engineers' Joint Council.

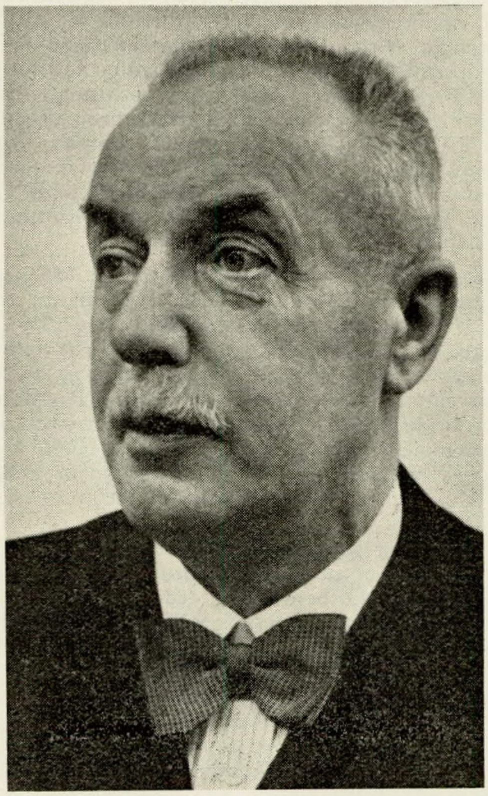
Mr. King was elected a Member of the Institute in 1931 and had served as Local Vice-President in New York since 1951.

MR. WILLIAM WILTON was born on 19th February 1880, being the youngest of the six sons of Mr. Bartel Wilton, the founder of the Wilton business. His first years of practical engineering were spent in the works of Wilton's Engineering and Slipway Company. At the age of eighteen, he went to England in order to complete his apprenticeship.

After his return to the Rotterdam Wilton yard in 1900, he was engaged in visiting ships in the harbour area for the inspection of repairs to be carried out and in obtaining repair orders for his firm. In this way he made many friends and had excellent contacts with captains and representatives of foreign owners. He succeeded in maintaining and extending such relations and contacts with the numerous foreign representatives of Wilton-Fijenoord had his special attention.

Thanks to his energy and kindliness, he enjoyed the goodwill of those with whom he did business both in his own country and abroad.

On 6th January, 1906, Mr. Wilton was appointed a managing director of Wilton's Engineering and Slipway Company (united in 1929 with the Shipbuilding and Engineering Company "Fijenoord", this combination working under the



name of Wilton-Fijenoord). After an industrious life he resigned from the managing directorship at the end of 1950, though he continued his connexion with the company as a member of the board of directors.

He died on 23rd October 1953, much regretted by all who had known him, for his excellent character and great business ability.

Mr. Wilton had been a Member of the Institute since 1924 and had represented the Institute in Rotterdam as Local Vice-President since 1938.

THOMAS WILLIAM ASH (Member 10605) was born in 1892. He served an apprenticeship with G. T. Grey, Holborn Engineering Works, South Shields, from 1908-15, and then spent two years as chargeman erector with the Wallsend Slipway and Engineering Co., Ltd. From 1917-21 he served as a seagoing engineer with Davies and Newman, Ltd., and Ropner and Sons, Ltd., and thereafter until 1931 with the Anglo-Saxon Petroleum Co., Ltd. He obtained a First Class Board of Trade steam certificate in 1922 (and a Motor Endorsement in 1936), and was promoted by the latter company through various grades to chief engineer. On leaving the Anglo-Saxon Company, Mr. Ash served in ships owned by Sir W. Reardon Smith and Sons until 1933, and in the Cliffside Shipping Company and the Moor Line until 1935, then with the Silver Line until 1941. Later, he was chief engineer with the Stag Line for several years, leaving them in 1948; at the time of his death by drowning at Swansea on 2nd July 1953, he was employed by John I. Jacobs and Co., Ltd., in m.v. *Hollywood*. Mr. Ash had been a Member of the Institute since 1946.

JAMES JOHN CANTLEY BRAND (Member 1849) was born in 1880, the eldest son of Captain Alexander Brand of Aberdeen. He served an apprenticeship with Burns and Twiggs of Rockhampton, Queensland, Australia, and then served as an engineer at sea for five years, obtaining an Extra First Class Board of Trade Certificate. From 1907-11 he was in private practice as a consulting engineer in Sydney and from 1911 until 1929 he served in the Royal Australian Navy, as engineer lieutenant until 1915, engineer lieutenant commander until 1919, engineer commander until 1926 and engineer captain from then until his retirement in 1929. During these years he served as engineer officer in the *Parramatta* and *Encounter*, he stood by the building of, and served as engineer officer in, the *Penguin*, he was fleet engineer officer of the *Adelaide, Melbourne* and *Sydney*, and from 1925-29 he was assistant to the naval representative and technical liaison officer in London, when he was a frequent visitor at the Institute. He was awarded the C.B.E. in 1929.

Captain Brand was the inventor of the Brand system of powdered coal burning and originator of the modern short flame burner; he established the firm of "B. and L." Powdered Fuel, Ltd., and left the Navy in order to devote all his time to the business. Throughout the second World War he was attached to the British Ministry of Supply as assistant inspector of armaments. He returned to Australia in 1949 and died on 12th September 1952.

Captain Brand was elected a Member of the Institute in 1906; he was the author of a paper entitled "Modern Contrivance in the Stokehold" which was presented at a meeting of the Institute in the 1908-09 lecture session. He was also a member of the Institution of Mechanical Engineers and the Institution of Naval Architects.

FRANK BROTHERTON (Member 8886) died 11th August 1953.

JAMES WILLIAM BRUCE (Member 6263) was born in 1880. From 1891-96 he served an apprenticeship with Higginson and Co., Ltd., Liverpool, and then served in ships of the Johnson Line, the Cunard Steamship Company, the British and African Steamship Company and R. P. Houston and Company and as chief engineer of a suction dredger with the Mersey Docks and Harbour Board. He obtained a First Class Board of Trade Certificate in 1907. From 1908-12 he was chief engineer and dredging superintendent in Burma, employed by the India Office. For the next two years he was guarantee chief engineer with W. Simons and Company and foreman engineer with the Cunard Steamship Company. Throughout the first World War, Mr. Bruce served in the Royal Engineers, first as sapper, then as lieutenant. From 1919-26 he was mechanical and general superintendent of the Queenborough Development Company and in 1927 went to India as mechanical superintendent of the harbour engineer-in-chief's department, Government of Madras, where he remained until 1938. In 1940 he obtained an appointment with the Air Ministry in London. Mr. Bruce died on 5th December 1952. He had been a Member of the Institute since 1929.

ALFRED CHARLES EVANS (Associate 11149) was born in 1898. His apprenticeship was served with the Blaenavon Co., Ltd., in Monmouthshire, from 1919-24; from 1922-26 he took a part-time day course at the Crumlin Technical College, Monmouthshire, and continued with an advanced course in electrical engineering at the same college until 1928. From 1926-34 he was working as shift engineer at the power station of the Blaenavon Co., Ltd. For the next three years he attended a degree course in electrical engineering at University College, Cardiff, and in 1937 obtained a B.Sc. degree; during this period he was also engaged in part-time work at Cardiff Docks for Swanson MacKay, electrical contractors, and from 1939-42 he was consultant engineer with the same firm. From 1942 until December 1951, Mr. Evans was a teacher of electrical engineering with the Wolverton Technical College, Buckinghamshire, when he left to join the research department of the Armstrong Siddeley Motors, Ltd., in Coventry, a position he held until his death in March 1953.

Mr. Evans was a Member of the Association of Mining, Electrical and Mechanical Engineers, an Associate Member of the Institution of Electrical Engineers, and had been an Associate of the Institute since 1947.

EDWARD HARROWER (Member 9830) was born at Bothkennar in Stirlingshire in 1889 and served an apprenticeship with the Greenock and Grangemouth Dockyard Company at their Grangemouth yard from 1903-08. He first went to sea in 1909 as second engineer of the s.s. *Perth,* owned by James Rankine and Company, but in 1910 secured employment with the Ellerman City Line as sixth engineer in the *City of York.* He was promoted through the various grades in several of the City Line ships until February 1922, obtaining a First Class Board of Trade Certificate in 1915, when he was appointed chief engineer of the *City of Lucknow*; subsequently he served as chief engineer of the *City of Karachi, City of Delhi, City of Marseilles, City of Venice, City of Paris, Cap Tourane* and the *City of Exeter.* He was serving in the *City of Paris* in September 1939 when she struck a mine off the East Coast and was one of the crew who reboarded the ship after she had been abandoned and brought her in to the Thames for repairs. In 1943-44, he stood by the *City of Edinburgh* during the period of her conversion to the Headquarters Ship H.M.S. *Lothian.* His last permanent sea-going appointment was as chief engineer of the *City of Exeter,* from 1945-50, though he served in a relieving capacity in the *City of Hongkong* and *City of Canterbury* after the *City of Exeter* was broken up.

Mr. Harrower retired from the company in 1951 owing to ill-health and died on 31st October 1953. He had been a Member of the Institute since 1944 and since the formation of the Merseyside and North Western Section he had attended their meetings as often as his failing health permitted.

FRED WOODWARD HOWELL (Member 13855) was born in 1898. He served an apprenticeship at H.M. Dockyard, Sheerness, from 1913-19, and then spent two years at sea as a junior engineer with the Shaw, Savill and Albion Co., Ltd. In 1921 he started his long association with the Royal Fleet Auxiliary Service when he was appointed junior engineer in the *Trefoil,* an Admiralty owned tanker built during the first World War. He served in many of the R.F.A. ships and was promoted chief engineer in 1935. Mr. Howell's sea service was interrupted on two occasions when he held appointments on the shore staff, for two years from December 1941-43 and from December 1948 until he died, after a long illness, from coronary thrombosis, on 11th October 1953. He was elected a Member of the Institute in 1952.

E. LESLIE HUNTER (Member 1596) was born at Arbroath in 1870 and was educated at Arbroath High School before being apprenticed to Alexander Shanks and Sons, Arbroath. After some experience with Richardsons, Westgarth and Co., Ltd., Hartlepool, as a fitter, he spent seven years at sea, from 1892-99, and obtained a First Class Board of Trade Certificate. He joined the ship and yacht repairing firm of Rait and Gardiner of Tilbury as an assistant engineer and after several years with them was appointed foreman engineer with Fletcher, Son and Fearnall; he was soon promoted under manager and, in 1910, manager. A large part of the company's work was on oil tankers at Thameshaven, Shellhaven and Purfleet; during the first World War they fitted out ships with guns and anti-mine and submarine equipment; salvage work from enemy action and collisions kept him busy night and day right through the war. After the war, and as a result of the slump in world trade, the business was sold to R. and H. Green and Silley Weir, Ltd., and Mr. Hunter was engaged with them in charge of the outside oil tanker repairs until his retirement in 1935.

Throughout the years of his retirement, he had enjoyed good health; he died on 11th December 1952. Mr. Hunter had been a Member of the Institute since 1902.

NORMAN IRVIN (Member 12609) was born in 1900. From 1916-22 he served an apprenticeship with Richardsons, Westgarth and Co., Ltd., Hartlepool, and during the same period attended evening classes at West Hartlepool Technical College. For a short time he went to sea as a junior engineer with Crosby, Magee and Co., Ltd., and afterwards served as second to fourth engineer with F. C. Strick and Co., Ltd., then as second and chief engineer with Joseph Constantine S.S. Co., Ltd., Middlesbrough. From 1932-45 he was assistant marine and engineer superintendent to Joseph Constantine and for the next seven years he had his own business as consulting engineer and marine surveyor to various Middlesbrough firms of shipowners and ship managers. Mr. Irving joined Lloyd's Register of Shipping in January 1953 and took up duty in Sunderland, where he was killed in an accident on 12th October 1953.

He had been elected to membership of the Institute in 1949.

GEORGE ALEXANDER MCGREGOR (Member 8864) was born in Auckland on 1st August 1893. He served an apprenticeship with George Fraser and Sons in Auckland from 1910-16, when he joined the New Zealand Shipping Co., Ltd., as junior engineer in the s.s. *Opawa,* and in their employment he spent the rest of his life. He obtained a First Class Board of Trade Steam Certificate in 1920 (with a Motor Endorsement in 1931), and was promoted second engineer in 1922. His first appointment as chief engineer was in the m.v. *Otaio* in 1932 and he sailed in this capacity subsequently in the m.v.s *Essex* and *Suffolk.*

Mr. McGregor stood by the building of the s.s. *Hororata* and sailed in her as chief engineer; when the ship was torpedoed off the Azores in 1943, he was awarded the O.B.E. for his part in the remarkable salvage operation which resulted in the return to port of the seriously damaged ship.

In 1949, he stood by the building of m.v. *Rangitoto,* sailing in her until December 1952, when he was granted sick leave. He died on 27th August 1953 at Auckland.

Mr. McGregor was elected to membership of the Institute in 1939 and served as Vice-President for the Merchant Navy from 1950 until his death.

HARRY PERCHARD WHITLEY (Member 4361) served his apprenticeship with the Mountstuart Dry Docks, Ltd., at Cardiff; he served in the Forces throughout the 1914-18 war, at Gallipoli and in France, and was twice mentioned in despatches. On his return in 1919, he was appointed assistant manager to John Shearman and Co., Ltd., at Barry, and continued in that position when, two years later, the company amalgamated with Mountstuart Dry Docks, Ltd. When the joint company was taken over by John Elliot of Elliot and Jeffery in 1926, Mr. Whitley was appointed assistant manager at Elliot and Jeffery's works at Barry.

When the Mountstuart Dry Docks, Ltd., and the Cardiff Channel Dry Docks, Ltd., with its associated companies, amalgamated in 1931, Mr. Whitley was appointed assistant manager of Barry Graving Dock and Engineering Co., Ltd., until, in 1934, he was promoted manager of the Mountstuart Dry Docks at Avonmouth. He continued in this position throughout the second World War and these services earned him the M.B.E., with which he was invested by the late King at the City Hall, Cardiff, in November 1945. In the same year he took over the post of manager of the Eastern and Tredegar Dry Docks at Newport, the position he held at the time of his death on 30th October 1953.

Mr. Whitley was a Member of the Institution of Naval Architects and had been a Member of the Institute since 1921.

PERCIVAL WARD WILSON (Member 7130) was born in 1872. His apprenticeship was served with Palmers Shipbuilding and Engineering Co., Ltd., and J. Dickinson and Sons, Ltd. He spent some years at sea and obtained a First Class Board of Trade Certificate of Competency. In 1932 he was appointed a surveyor to the Salvage Association of London and went to America, where he remained until his retirement early in 1952. Mr. Wilson had been in failing health for some time, however, and died on 28th April 1952. He had been a Member of the Institute since 1932.