GAS TURBINES IN THE ROYAL NAVY, 1970 TO 1973

BY

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Introduction

This paper falls naturally into two quite distinct parts. The first and longer part provides a review of development work, trials and experience of gas turbines in the Royal Navy over the last four years. It thus takes up the story from a previous paper(1) given by my predecessor in the Ministry of Defence. The second part of the present paper discusses some of the logistic and management problems involved in the support of a fleet of gas turbine driven ships.

The scope of the first part of the paper requires some qualification. It is not intended to be a log or register of events and problems that were important at the time; nor is it a true history, tracing the sequence of ideas in the engines' development and their inter-relation. Rather it is a record of occurrences which, though they may have happened up to four years ago, are still of current interest to engineers. Not only the engines themselves but also the associated intake and uptake ducting, demisters, etc. are considered.

The engines principally referred to in this paper are three: the Olympus TM3B, the Tyne RM1A and the Tyne RM1C. They are all manufactured by Rolls-Royce (1971) Ltd. Particulars of the first two have been published(2) but nevertheless it is worth reviewing their salient features. All three have been derived from aero-engines with the consequent advantages of low weight, easy removal and long-proven reliability of all those parts that have not been modified in the course of marinization.

The Olympus TM3B (FIG. 1) has a nominal power of 28,000 b.h.p. (bare engine, no external losses) with a HP turbine entry temperature of 1220°K at 15°C ambient temperature. As with all these engines, the precise power when installed in the ships is classified and cannot be released. The TM3B is derived from the Olympus 201 aero-engine which, with changed materials and other modifications, forms the gas generator. The single-stage power turbine was specially designed from new for the marine application and is not permanently attached to the gas generator. They are both mounted on a common bed-plate and built up into a standard module together with their control systems, acoustic enclosures, fire-extinguishing systems, etc.

The Tyne RM1A (FIG. 2) has a power (before installation) of 4250 b.h.p. with a TET of 1154°K at 15°C ambient conditions. It too has been developed from an aero-engine, the Tyne 18, which is a two-spool propeller engine. Very considerable change was involved in its conversion, including physical rearrangement as well as different materials. Like the Olympus, it is installed in a standard module but, in this case, because of the high power turbine speed, the module includes a primary reduction gearbox to bring the output speed low enough to be acceptable in the ship's main gearbox.

The Tyne RM1C, at 5340 b.h.p., is still undergoing full development and will be described at a later stage in the paper.

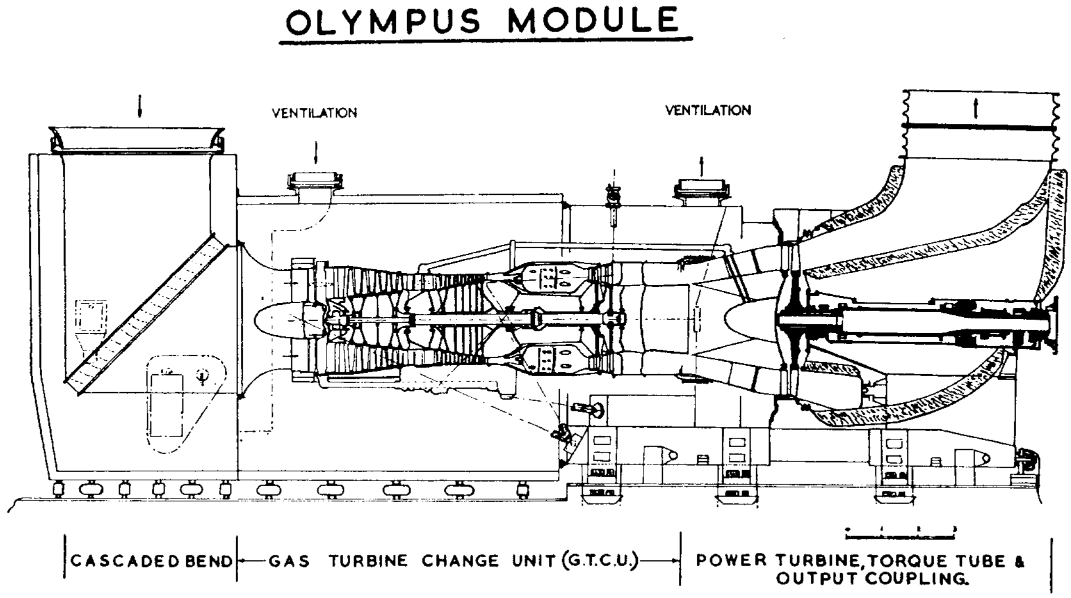

FIG. 1—OLYMPUS TM3B—SECTIONAL ARRANGEMENT

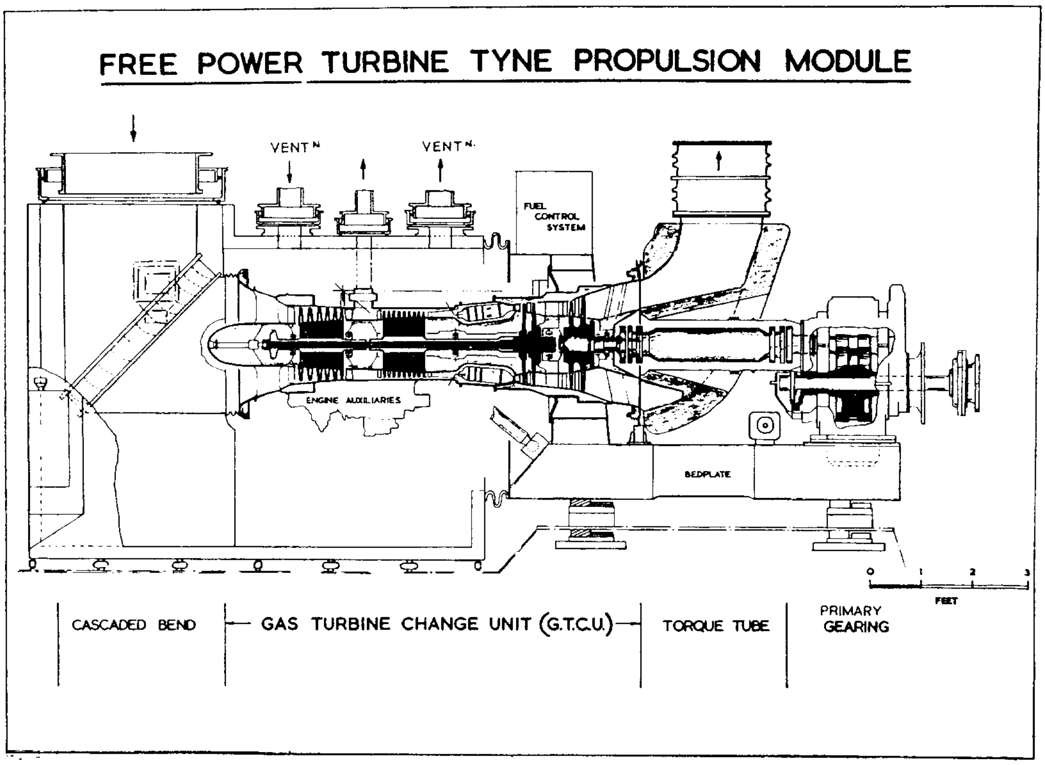

FIG. 2—TYNE RM1A—SECTIONAL ARRANGEMENT

Olympus and Tyne engines are currently fitted in the Royal Navy's new Type 42 destroyers (FIG. 3) (H.M.S. *Sheffield*, H.M.S. *Birmingham*, etc.) and Type 21 frigates (FIG. 6) (H.M.S. *Amazon*, H.M.S. *Antelope*, etc.). In both classes the machinery installation (FIG. 4) is almost identical, having one Olympus and one Tyne geared together on each of two shafts. The arrangement is COGOG (Combined Gas Or Gas) with the shafts being driven alternatively by the Tyne, up to cruising speeds, or the Olympus, at higher powers. The engines are connected to the main gearing through synchro self-shifting clutches and the operation of these is linked with the control of the engine speed and propeller pitch in a single control system. A similar engine fit will be used in the later class, Type 22 destroyers. Olympus engines alone will power the new through-deck cruisers of over 16,000 tons.

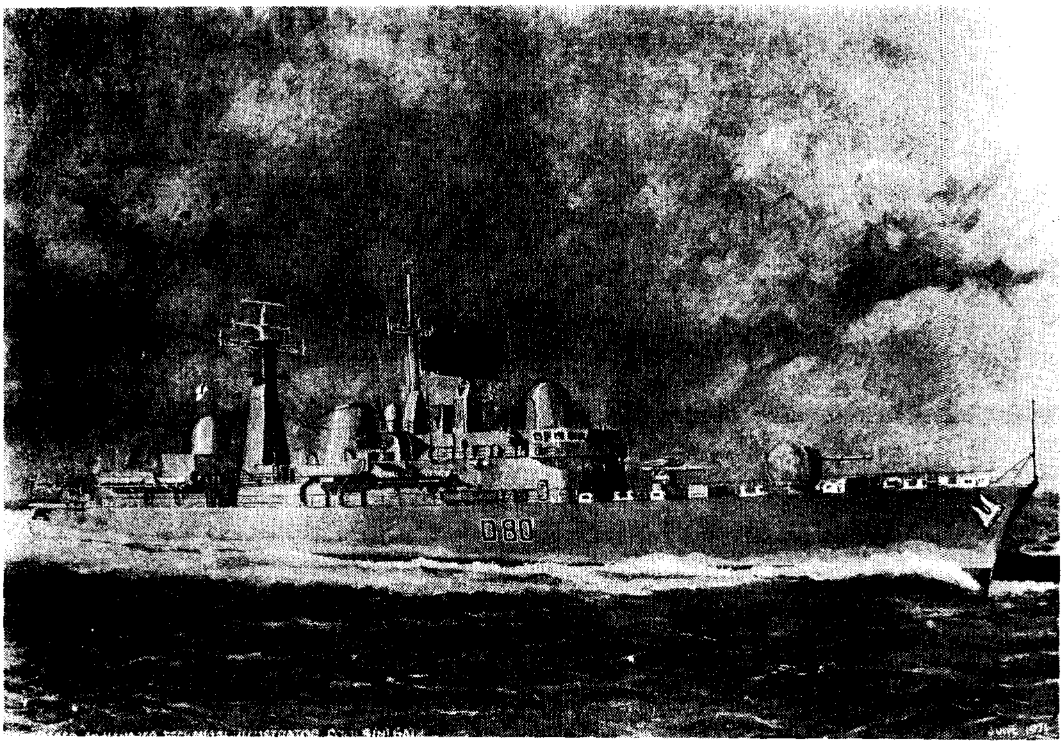

FIG. 3—H.M.S. 'SHEFFIELD'—AN ARTIST'S IMPRESSION

Before embarking on the main body of the paper, mention should be made of the Royal Navy's continuing experience with the older gas turbines. The G6 engine of 7,500 b.h.p., designed *ab initio* as a marine engine, first went to sea in 1961 in the COSAG installation H.M.S. *Ashanti* (2800 tons); 39 of these engines are still in service, having built up 80,839 hours of running in 15 ships (8 destroyers and 7 frigates).

Olympus

As reported in a previous paper(1), the first marine Olympus to go to sea was the earlier version, the TM1A, in H.M.S. *Exmouth* in 1968, where it was in a combined installation with two Proteus gas turbines (3560 b.h.p. each) as cruise engines. This ship has continued to give good service as an operational warship, not just as a trials ship. When the last Olympus gas generator was removed for inspection at over 3000 hours, it was found to be in excellent condition.

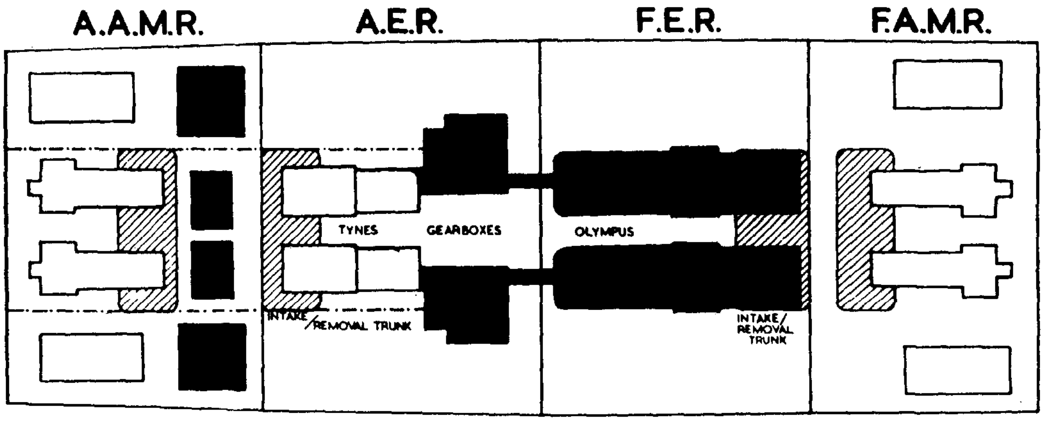

FIG. 4—LAYOUT OF GAS TURBINE MACHINERY IN TYPE 42 DESTROYERS AND TYPE 21 FRIGATES

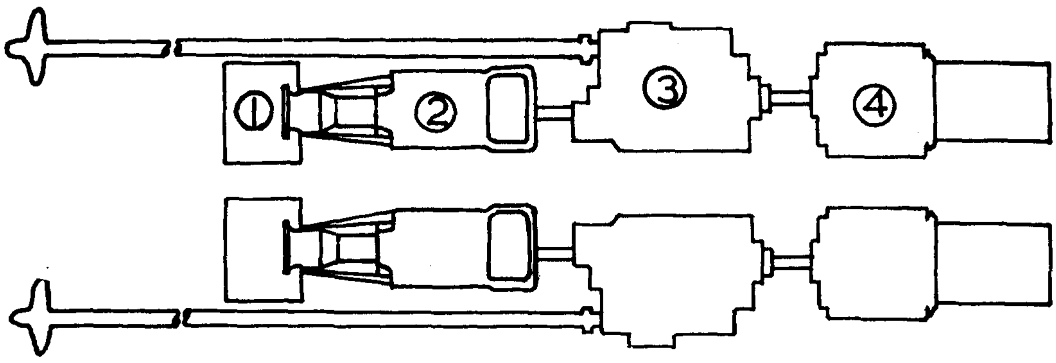

FIG. 5—LAYOUT OF COSAG MAIN MACHINERY IN H.M.S. 'BRISTOL'

(1) Air Intake
(2) Gas Turbine
(3) Gearbox
(4) Steam Turbine

TM1A engines have also been in use for a year in the COSAG plant (FIG. 5) of H.M.S. *Bristol*, a Type 82 destroyer of 6,000 tons. Here, as in H.M.S. *Exmouth*, the design of the ship's propellers, shafting and gearing, because it was basically the same as that of the earlier County Class, limited the output of the Olympus engine to 15,000 b.h.p. This corresponds to a turbine entry temperature of only about 1040°K, so it does not provide a severe test of the resistance of the turbines to hot corrosion in marine conditions.

Very similar engines, Olympus TM2s which use the same turbine materials, have been running since 1969 in frigates of the Iranian and Malaysian navies and have apparently met with no problems. They have been operated at up to about 22,300 h.p. which corresponds to a turbine entry temperature of 1125°K, though the extent of their running is not known.

The most extensive experience of the A rating engines has been in the 64 used by the Central Electricity Generating Board of England and Wales(3). Between them these have amassed some 180,000 hours of running. Some of this has been in the salt laden atmosphere of coastal power stations.

The more highly rated engine, the TM3B which forms the basis of all the Royal Navy's new installations, has been at sea in H.M.S. *Amazon* (FIG. 6) since 1973. Its main development was completed in 1970 and since then some further 2393 hours of accelerated endurance testing have been carried out for

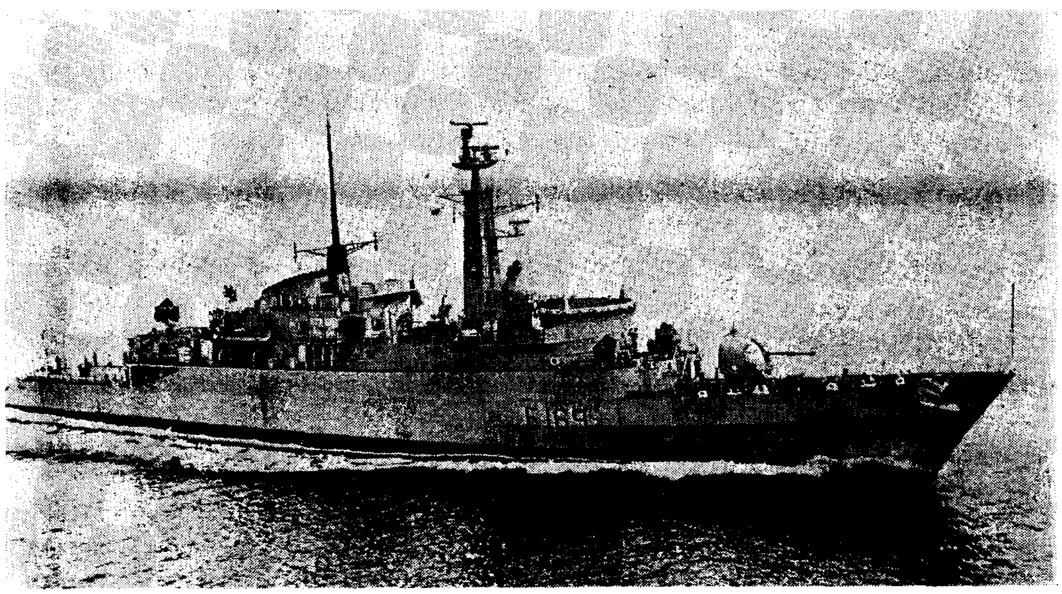

FIG. 6—H.M.S. 'AMAZON'

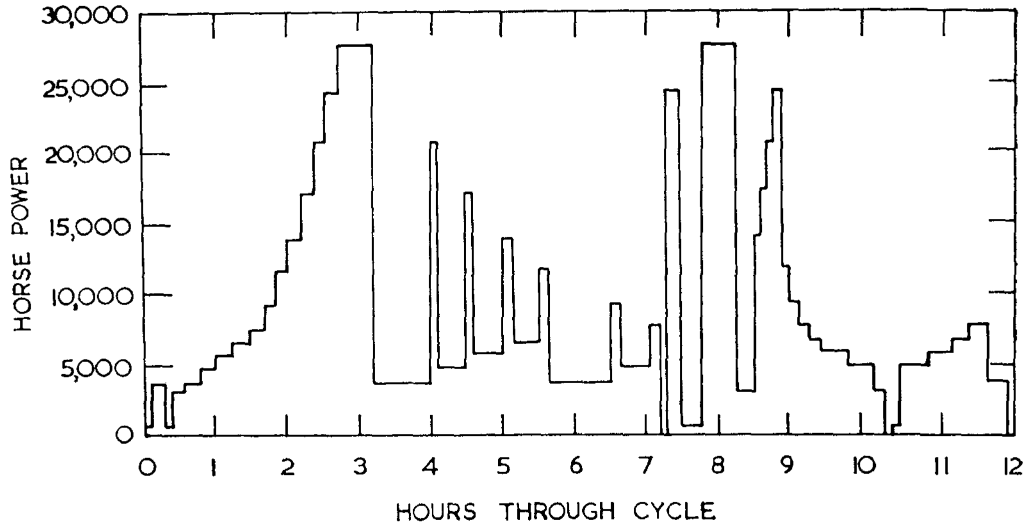

FIG. 7—OLYMPUS TM3B SHORE TRIAL—CYCLIC RUNNING SCHEDULE

the Navy on the Ansty test-beds of Rolls-Royce (1971) Ltd. For these trials the engine was installed with intakes and uptakes precisely similar to those in the Type 42 destroyers. A cyclic pattern of running (see FIG. 7) was adopted, based on the operating pattern of the ship but including a higher proportion of time at full power and more frequent alteration of the engine power. This was to ensure that the hot parts of the engine were subject to their full temperature for as long as was consistent with producing frequent and severe thermal cycling. For most of the time, salt was injected in the air (in the proportion 0·01 p.p.m. of sodium chloride) and also in the fuel (0·3 p.p.m. of sodium); this results in the equal quantities of sodium being put into the fuel and the air.

TM3B engines have also been run at Ansty in the shore test facility for the British through-deck cruiser and in the shore trials of the Royal Netherlands Navy frigate at Flushing. In both these cases it is the entire propulsion unit with its gearing, clutches and control system which is the subject of the testing, and the gas turbines spend much of their time responding to the sometimes violent requirements of manoeuvring, etc. Another Olympus TM3B is, at the time of writing, being installed in the Naval Marine Wing of the National Gas Turbine Establishment at Pyestock. Its purpose is to provide long term endurance running, again to a cyclic pattern and with salt injection, and thus to build up experience more quickly than will be the case in operational warships. It will be run under direct naval supervision which ensures that its satisfactory performance is not dependent on special skills, familiarity and experience that would not be available in ships.

During 1972, an Olympus module, mounted in a special barge, was subjected to a test by underwater shock. The engine was running for some of the tests and stopped for others and the results were completely satisfactory. The precise accelerations which the engine will withstand cannot be released for publication, but it can be said that the special cantilever support system for the aero-derived gas generator itself absorbs some of the shock, so the attentuation required of the engine mounts is less than is necessary with other comparable engines.

TM3B Technical Problems

A few of the technical problems encountered with the TM3B in the last four years will now be discussed. Those that arose in the earlier stages of development were described previously(1), but others have arisen under the ardouous conditions of the cyclic salty shore trials.

Salt Injection

A difficulty was experienced here, not with the engine, but in the testing technique. To have a realistic effect, the salt water added to the fuel must be present in a fine dispersion. If it is not, it tends to separate out in the fuel system, giving unrepresentative contamination and causing excessive corrosion in the pump. Injection by conventional means did not achieve the intimate mixing required but the method now used results in a maximum water droplet size of 5 microns. The water enters the fuel through the eye of a special additional fuel pump; the fuel/water mixture is then passed through thirteen 0·050 inch (1·3 mm) holes, followed immediately by a plate which forces the flow to turn through ninety degrees. The resultant shearing action provides the necessary fine dispersion.

Corrosion Induced Fatigue of Compressor Blades

As originally designed, the Olympus TM3B compressor had both its rotor and compressor blades in a chromium martinsitic 'stainless' steel. Testing with salt in the intake air showed that its fatigue strength under these conditions was reduced to about half and fatigue failures did in fact occur in the first stage blades. These were not due to true corrosion fatigue but the fatigue cracks were initiated at corrosion pits which evidently formed when the engine was shut down and moisture condensed on the cold and slightly salty metal surfaces.

Five corrective actions were taken to prevent recurrence and have been successful:

(*a*) the compressor is water washed whenever it is to remain stopped for more than 4 hours.

(*b*) this wash is followed by spraying with a water-dispersant preservative oil (WD40).

(*c*) the blades, after manufacture, were shot-peened, aquablasted and coated with Rockhard lacquer to give a corrosion resistant surface.

(*d*) the rotor blade material was changed to a titanium alloy.

(*e*) the first row of stator blades was shrouded.

As an additional safeguard and to prolong the life of the stator blades so that they do not need replacement at each overhaul, it is intended to change the material to Inco 718 in future engines.

Power Turbine Thrust Bearings

Early in the Olympus development programme, the tilting pads from the power turbine thrust bearing tended to develop a faceting or cracking of the whitemetal surface attributable to thermal cycling at high metal temperatures. Directed spray lubrication was substituted for the previous flooded chamber system but high pad temperatures were still encountered. The thrust pads at this time pivoted about their centres and an improvement was obtained when they were replaced by offset pivot pads. These two modifications together have enabled the bearing to operate successfully not only under high steady loads but also under the transient conditions of manoeuvring.

It is expected that the aluminium-tin bearing metal AS45 will be resistant to faceting under all conditions, and thrust pads of this material are currently being evaluated on shore trials engines. If adopted generally, they should enable the bearing to continue to operate safely even if the oil supply should be reduced for any reason.

Ventilation of the Acoustic Enclosure

The engine carcases of the Olympus and the Tyne are surrounded by acoustic enclosures to reduce noise both within the machinery space and transmitted to the rest of the ship through the bulkheads. As these enclosures prevent the heat radiated from the engine being dispersed into the machinery space, special enclosure ventilation is needed. It was found on trials that the heat released from both engines was substantially greater than had been predicted.

Two lines of action were followed:

(*a*) A radiation shield was placed round the hottest parts of the engine, and a controlled volume of air was passed within the shield. The remaining air was judiciously directed where it was most needed in the other parts of the enclosure. In short, by allowing some parts of the enclosure to remain at high temperature and ensuring that the critical parts were kept cool, the best use was made of the air available.

(*b*) The quantity of cooling air was increased. This increase is limited ultimately by the size of the ventilation ducting, however large a fan is fitted. In conjunction with (*a*), it is, however, sufficient.

In the course of these investigations it was found that cooling air is needed in the enclosure only when the engine is running; it is not necessary after shutdown as had been anticipated. This removed an important constraint from the ventilation design and made it possible to make the engine ventilation self-contained, using no fans or separate ventilation ducts at all. The air can be drawn from the intake duct and drawn through the acoustic enclosure by utilizing the depression in the engine exhaust volute. Such a system (FIG. 8) has been designed and successfully tested on a shore trials engine.

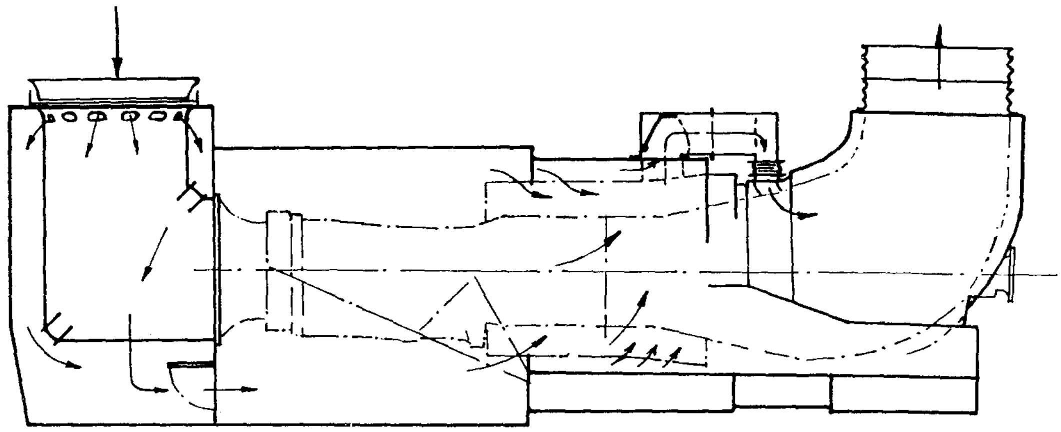

FIG. 8—OLYMPUS TM3B, WITH THE ACOUSTIC ENCLOSURE COOLED BY AIR DRAWN THROUGH BY THE EXHAUST DEPRESSION

Tyne RMIA

The timing and testing of Tyne RM1A development has been very similar to that of the Olympus and it too has been at sea since 1973 in H.M.S. *Amazon*. The RM1A was marinized direct from the aero-engine(1) without any intermediate stage of an industrial version or an earlier mark of marine engine being used at sea apart from two in US hydrofoils. Several development engines were used concurrently for main development which ended in 1972. This was followed by 2500 more hours of accelerated cyclic salted endurance running in the configuration of the Type 42 installation. Further such running is taking place under naval supervision at the National Gas Turbine Establishment from 1973 and at the time of writing 1500 hours had been achieved there. In the course of this running, opportunity is being taken to compare the effect of different intervals between compressor washing. The Netherlands trials at Flushing, already mentioned, also include a Tyne. The Tyne engine has also been subjected to a satisfactory test of its resistance to underwater shock.

RMIA Technical Problems

As would be expected, several problems of technical interest arose in the development of the Tyne RM1A and in the earlier stages of its endurance running. Problems were also experienced with the ventilation of the Tyne acoustic enclosure similar to those already described for the Olympus.

Power Turbine Rotor Blade Failure

Although this failure occurred in a blade with an experimental coating and not in a standard production one, nevertheless a lesson can be learned from it.

The HP turbine rotor blades (in Nimonic 108) have always been afforded a measure of protection by applying an aluminized coating during manufacture. As part of an investigation into anti-corrosion measures one of the development engines was built with similar coatings on the blades of all the turbines. The blade that failed was a 1st stage power turbine rotor blade and it was found that the aluminized layer had shattered at the trailing edges, causing cracks to propagate into the base metal. It is now appreciated that the aluminized layer is brittle at the operating temperatures (about 930°F) unless it has been diffused into the base metal by heat treatment. The HP turbine blades run at a temperature which causes their coatings to diffuse while in service. Nevertheless for prudence, a diffusion process has been introduced with the manufacture of all the blades.

Excessive Bearing Temperature in the Primary Gearbox

The Tyne power turbine and hence the high-speed pinion of the primary gearbox runs at a maximum speed of 12,900 r.p.m. There was little or no experience with plain bearings at this speed, but peripheral speeds of 240 ft./sec. were thought to be acceptable. As soon as the gearbox was run, however, it was clear that both the bearings of the high-speed pinion were running far too hot.

The direct approach of reducing perhipheral speed by a decreasing of the journal diameter was not possible because of the adverse effect on shaft stiffness. So the bearing length was increased from $2\frac{1}{2}$ in. to 3 in. giving a 19 per cent. increase in bearing area which reduced the temperature sufficiently. Subsequently, the temperature was further reduced by cutting a circumferential groove in the unloaded half of the bearing and there is now sufficient margin to accept the additional loads and speeds of the uprated engine.

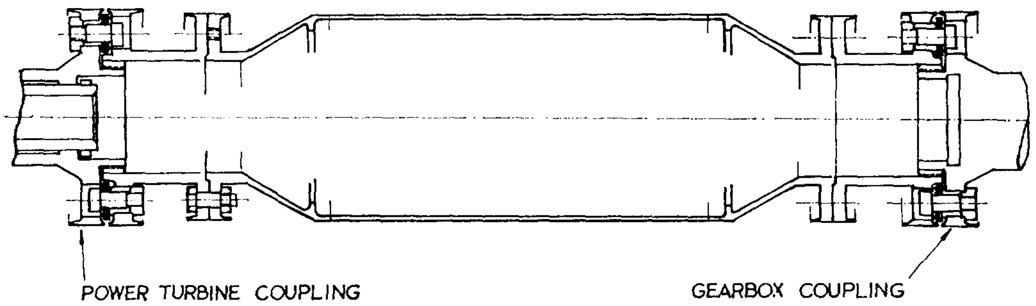

FIG. 9—TYNE RM1A—MODIFIED HIGH SPEED COUPLING SHAFT

High Speed Torque Tube Vibration

The Tyne RM1A power turbine is connected to the primary gearbox by a high-speed coupling shaft (FIG. 9), incorporating a torque tube, which runs at 12,900 r.p.m. In the uprated RM1C its speed will be 13,970 r.p.m. It had always been realized that it would be difficult to design this to avoid critical speeds and, in an endeavour to keep it as light as possible, the end couplings had been made of aluminium alloy. These distorted on trial due to the running temperature in its vicinity being higher than expected, and the end couplings were therefore rebuilt in steel making the whole shaft heavier. At about this time, the critical speed was determined from engine trials, showing that the stiffness of the pinion bearing support was in fact less than calculated.

Thus for both reasons it was vital that the overall weight of the coupling shaft plus pinion be reduced. This was achieved to the extent of 20 lb. by:

(*a*) machining an axial lightening hole in the pinion.

(*b*) reducing the diameter of the flanges at the torque tube coupling joint at the end away from the engine.

A stronger steel was also used.

Future Development Work

Although the Olympus and Tyne are now both in service in the Fleet, work ashore has not stopped. It follows two main lines. Firstly, as already mentioned, endurance running under deliberately arduous conditions is continued at the NGTE to accumulate running hours faster than at sea and hopefully to encounter any long term defects before they occur in ships. Secondly, there is a continuing programme of further development or 'product improvement'. This is analogous to similar continuing work on aero-engines even after they have been in service for many years. It serves two main purposes:

(*a*) To lengthen the time between overhaul, thereby providing not only greater ship availability but also saving overall cost by the reduced cost of fewer overhauls and the smaller number of spare engines bought to replace those removed for overhaul.

(*b*) To lengthen the life of particular components so that the cost of spares is reduced.

Thus, this further development is as much as anything a means of saving money; it also increases the operational availability of the ships, it ensures that expertise is maintained ashore where it is available for trouble-shooting, and it provides a stimulating job for engineers!

Tyne RMIC

The Tyne RM1C or uprated Tyne, now being developed, has considerably more power than the RM1A even under temperate conditions (i.e. 25 per cent., or 5340 b.h.p. instead of 4250 b.h.p. at an air temperature of 15°C). Under tropical conditions with inlet air at 30°C, however, the power increase is much more marked, namely 38 per cent. from 3660 b.h.p. in the RM1A to 5040 b.h.p. in the RM1C.

The difference between the two engines lies almost solely in the turbine. The compressor is identical and the other changes are relatively minor such as a new fuel pump of greater capacity. The RM1A engines will, therefore, be able to be converted to RM1C during overhaul by the incorporation of a single large modification. Also, once the change is made, all new Tynes will be made to that standard with little effect on the production line.

The uprating is essentially a matter of increasing and improving the cooling of the compressor turbine blades. This allows the TET to rise by 126° to 1280°K, without substantially increasing the blade metal temperatures. The newly developed HP turbine blade is of a three hole design with once-through cooling air flow, ducted internally from the HP compressor discharge. This blade is cast in corrosion resistant Inco 738 with a suitable coating as extra protection.

Full development of the RM1C has been in progress since 1972. So far it has been limited to design work, together with rig testing of the combustion system, corrosion and thermal shock testing and casting trials of the blade material, and comparative corrosion trials of a large number of protective coatings. More fundamental work on the mechanism of corrosion is also in hand, sponsored by the Royal Navy(4). The first complete development engine is scheduled to run in 1974; a second development engine will follow shortly after the first and it is also intended to carry out endurance trials at the National Gas Turbine Establishment.

An interesting problem in technical management arose in the selection of the material for these turbine blades. The choice had to be made between fully proven materials that were not the best available and the far more promising materials whose properties were insufficiently known. In the event Inco 738 (a high chromium content castable nickel alloy) was selected because of its high corrosion resistance coupled with adequate strength; it had also been used successfully in the Allison 501K15 and other engines. However, at the time the decision was made (early 1973) there were still many unknowns about it. In particular, was it amenable to casting in complex shapes for the very small Tyne blades? Also, what was its behaviour under thermal stress in thin sections? In view of these uncertainties and the dependence of the whole RM1C development programme on the suitability of the blade material, it was clearly prudent to order an alternative material as a back-up. Now the requirements of temperature and corrosion resistance and strength in the engine did not leave many alternatives and none of them seemed as likely to be suitable as the material already chosen. So the anomalous situation thus arose where the stand-by material (Mar M 432), instead of being a safe but unexciting alternative, was in itself probably less likely to be successful. Nevertheless this back-up material served a useful purpose. Its problem areas were not necessarily the same as any that might be identified with Inco 738. The chosen material had already been selected on the basis of its known and expected properties; it was the unexpected that needed to be guarded against and any different alloy would in all probability have different characteristics in whatever area difficulties might be encountered. In other words, the alternative material was an insurance policy but not a completely safe one. Happily the Inco 738 chosen as the best material has justified expectations so far and further testing has only served to confirm and extend the previous findings.

Uptakes and Silencers

The ducting for gas turbine intakes and exhausts presents its own problems. The fact that disturbed flow at the inlet can lead to blade excitation and hence failure in the compressor was learned the hard way in H.M.S. *Exmouth*(1), and subsequent designs have avoided this. Problems can also arise with the ducts themselves, particularly the exhaust duct or uptake, because of the immense amount of energy contained in the gases. Much of this energy is of course still present as heat and velocity in the gas as it leaves the stack. Even so, there is a vast amount of gas power there which can be transferred to the uptake structure if the gas feels itself to be ill-treated. It is the inertia of the gas which is most liable to give trouble and, as the energy dissipated varies with v^2, the cross-sectional area of the duct clearly is of great importance. Unfortunately, ship-

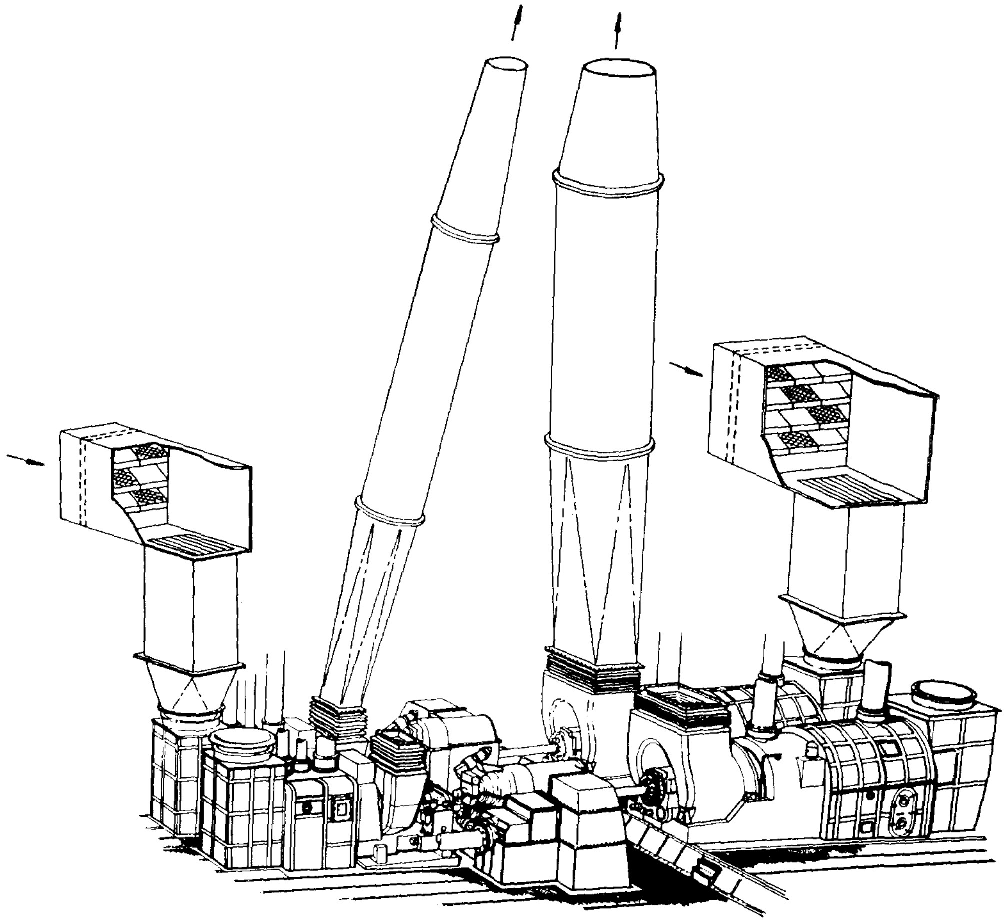

FIG. 10—TYPE 42 DESTROYER GAS TURBINE INLET AND EXHAUST DUCTS

building constraints militate against large ducts because of the great importance of space in warships, and they further aggravate the ducting problem by necessitating tight corners, short diffusers and inadequate settling lengths (FIG. 10).

The difficulties can therefore be very severe, particularly if the duct sizes are reduced to a minimum in order to benefit the ship design as a whole. Equally important, from the point of view of this paper, is the fact that they are not really amenable to theoretical prediction. For this reason, not only must every uptake be model tested at the design stage, but several options need to be included in these tests so that:

(*a*) the most promising can be selected,

(*b*) areas of particularly bad flow can be identified for improvement.

Model testing thus serves a very useful purpose but it cannot alone guarantee the successful functioning of a full-scale uptake. In particular, it cannot deal adequately with resonant frequencies; nor can it show whether the best design selected from a series of options is necessary good enough. This can be done by trials of full-scale ducts with a real engine. Such full-scale testing has been done, in addition to model testing, for the Type 42 destroyer and is being done now for the through-deck cruiser (with its very long 'aircraft carrier' shape ducts) and the Type 22 frigate.

The exhaust silencer is in a particularly vulnerable position, sited as it must be in the middle of the high-energy gas stream. Not only must it be structurally sound and unaffected by resonance, like the rest of the uptake, but also the silencing material, the infill of the silencer, must be capable of withstanding the buffeting and the temperature while still being sufficiently exposed to the hot gas to fulfil its function of absorbing noise. Here again, without actual full-scale trials it cannot be known whether the best is good enough; indeed it cannot even be known with any certainty which is the best.

In the Royal Navy trials at Ansty, the centre one of the three silencer splitters in the Type 42 uptake was fitted out with a 'Neapolitan' selection of 44 varieties. This was made up in various combinations; two alternative infills, surrounded by inner containers in six materials, some of them in three different mesh sizes, in two alternative outer casings. By examination after 1554 hours of running, it was possible to determine with confidence the most cost-effective combination of materials. Irritatingly, a decision was also needed for another shore trials engine installation before the full trial was complete and so before the samples could be cut up for examination. Nevertheless, it was possible to make an adequate selection by visual examination, though doubtless the extra margin of safety applied may have resulted in an unnecessarily expensive choice.

Demisters

It is now generally appreciated that the design of air inlet separators or demisters is of paramount importance in ensuring adequate life of the gas turbines. This was high-lighted by experience in H.M.S. *Exmouth* and in the Euroliner class of container ships (5).

The major problem does not arise with actual sea spray, as was once expected, for this consists mainly of relatively large droplets which are easy to stop. The most trouble is caused by the very small particles of moisture or dry salt which persist in the marine atmosphere even in calm weather and at considerable heights above the sea. These droplets may be as small as 5 microns or less in diameter and they cannot be stopped by inertial separation alone.

Most Royal Navy ships at the present time are fitted with an obsolescent type of demister consisting of two stages. An inertial vane separator is followed by inclined pads of a knitted mesh made of polypropylene. This second stage coalesces the very small droplets so that they can be drained away as water. Although this type of filtration is adequate, it suffers from the disadvantage of size in addition to not being quite as effective as more recent designs.

The currently approved demister consists of three stages (FIG. 11). Large droplets are separated by the first vane separator; the very small ones are then coalesced in the woven polypropylene pads forming the second stage and the resultant larger drops are then removed by a third stage, which is again an inertial vane separator. The felt pads in their frames are clipped directly onto the face of the third stage filter units. A two-foot (0.61 m) space between the first and second stages allows any temporary breakthrough of water, such as could arise if the front of the demister were to be struck by a wave, to fall to the deck before reaching the second stage; it also affords access for maintenance. The separators are made in standard units measuring 70 in. × 40 in. (1·78 m × 1·0 m), for logistic simplicity. The inlet of one Tyne engine is fitted with a bank of two standard units, and the Olympus inlet has eight (FIG. 12).

The selection of the basic three-stage separator system and its subsequent development required a test rig, improved techniques of particle measurement, and a greater knowledge than then existed of the way in which salt was actually present in the marine atmosphere. These needs were filled by a small group in the Naval Marine Wing of the National Gas Turbine Establishment. They have continued to monitor the performance of separators offered by industry so that the Navy can take advantage of any significant advance that may be made. Among other tests was one carried out at the request of a sub-contractor of Litton Industries on a separator which may be fitted in the U.S. Navy DD963

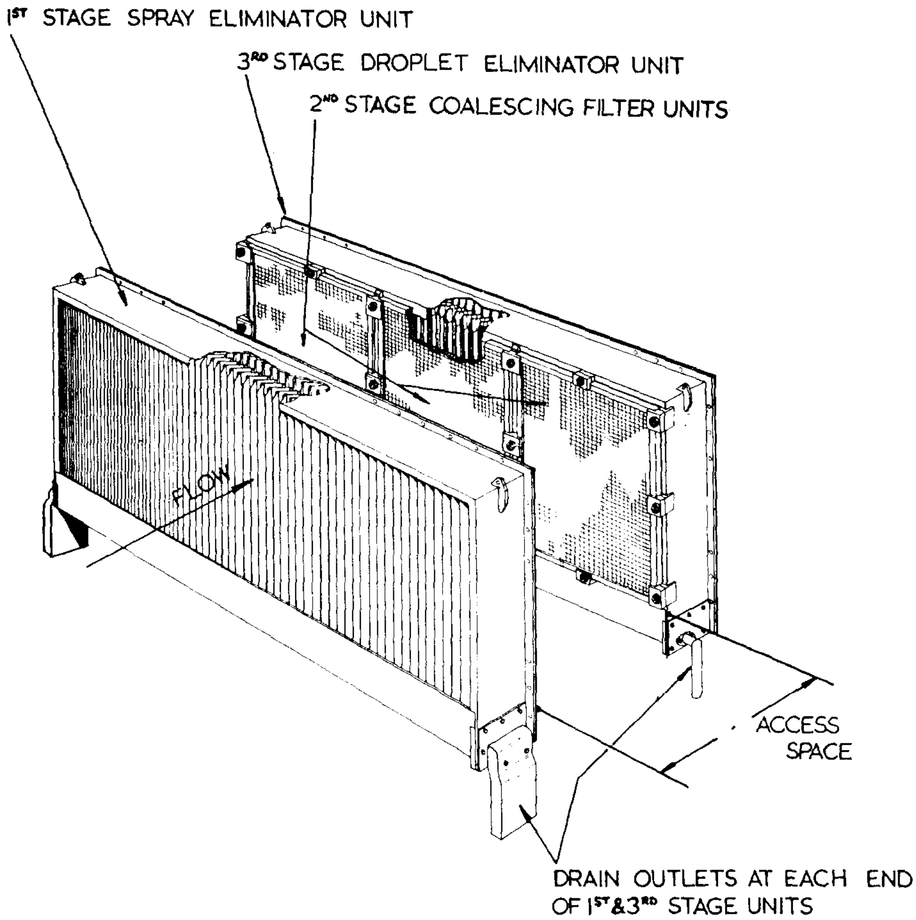

FIG. 11—THREE-STAGE DEMISTER—A STANDARD UNIT

Class destroyers. Another function of this separator group at NGTE is to carry out trials of separators installed in new ships. On one occasion, the cause of an apparently ineffective separator was found to be an error in installation; daylight could be seen round the outside of the unit!

It is worth considering very briefly the necessity for good salt separation, for it could be argued that the cost, liability to block with snow, top-weight and particularly pressure drop made them undesirable. Could not the need be obviated by changing the materials of the engine so that corrosion ceases to be a problem? After all, this is being done with the compressor materials in the Tyne and Olympus. Although it is probably feasible to make the compressors really stainless, this is certainly not true of turbines. There, the materials which are particularly corrosion-resistant at high temperatures either have insufficient strength or else their thermal shock or casting properties make them unsuitable. Even if there were no problem with corrosion, the presence of salt in the engine would still be deleterious because it would affect the performance. With demisters fitted, the compressor performance still reduces perceptibly between washes and this is especially significant in small engines where the blade dimensions are small. Increased salt admission would increase this rate of salt build-up so that compressor washing would need to be so frequent as to be operationally unacceptable.

LOGISTIC SUPPORT

The last part of this paper deals briefly with the logistic support of ships propelled by aero-derivative gas turbines.

On the face of it, the situation might seem to be no different with gas turbine

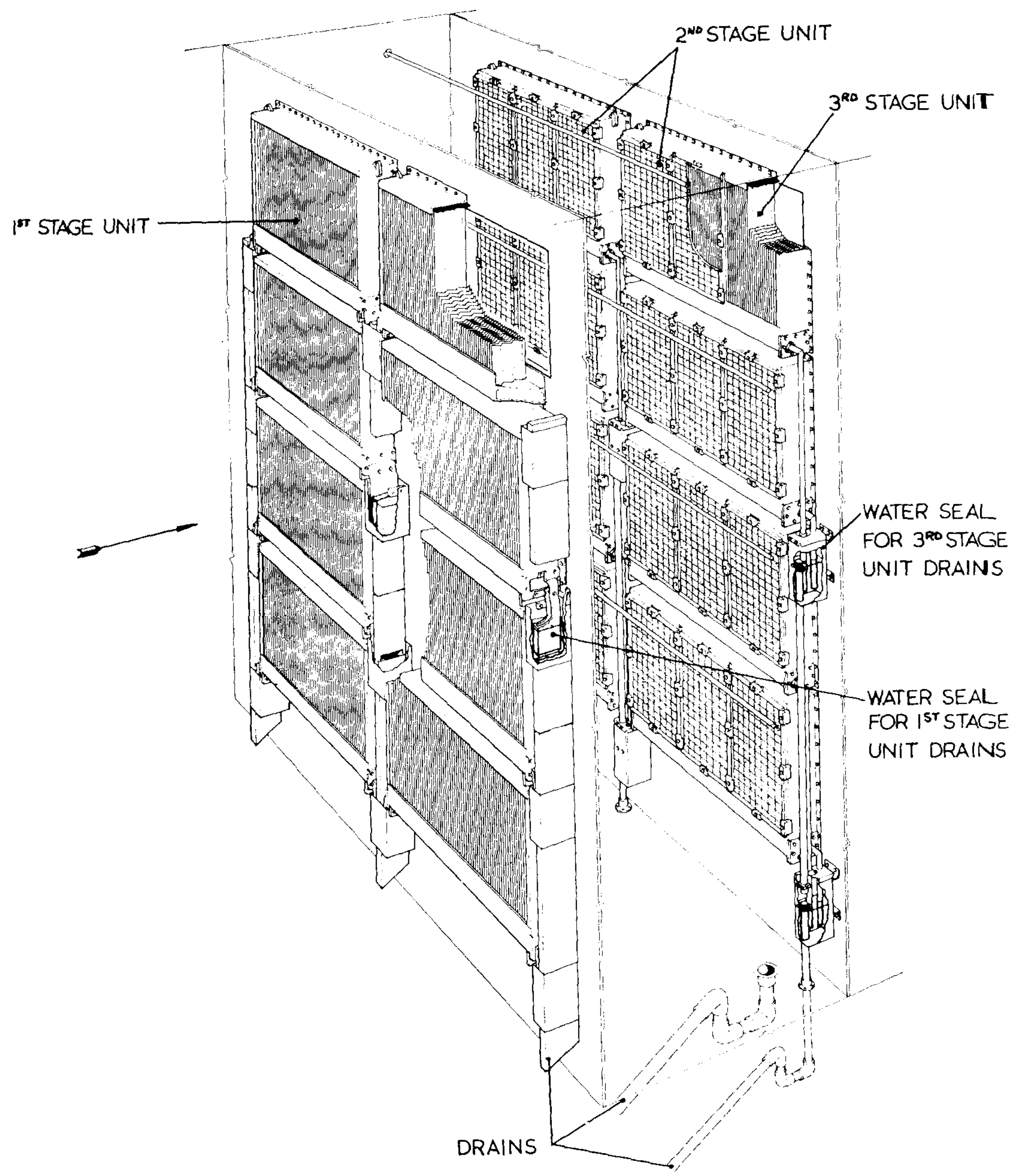

FIG. 12—OLYMPUS INTAKE DEMISTERS, COMPRISING EIGHT STANDARD UNITS

ships than with any others. Ships' engines have surely always been liable to need repair and ships' engineers have always needed spares which are not held on board. The difference lies in the following factors:

(*a*) Gas turbines, in ships as in aircraft, are liable to random failures requiring replacement between planned overhauls.

(*b*) A defect on a gas turbine generally requires the engine to be removed before it can be rectified.

(*c*) Aero-derivative gas turbines can be removed and replaced easily and quickly.

(*d*) Once a main propulsion gas turbine is defective, the ship's capability is reduced either in power or range.

(*e*) The spare engines, although fully interchangeable between ships, have 'personalities' in the shape of lives and modification states which may make them more suitable for one duty rather than for another.

(*f*) Not only is down time of ships expensive but, because of the high cost of gas turbines, so is the down time of their engines.

These factors can be combined into three: gas turbines can be changed quickly, they must be changed quickly, and the changes will often be at short notice.

So, a fresh approach to gas turbine logistic support in the Royal Navy was made in 1970. Because many departments and specializations had an input into this work and since all of them would be affected by the outcome, it was essential to use corporate planning from the outset rather than remain subject to the restrictions of conventional line management. For this reason, a working party was set up under the author's chairmanship to see what needed to be done, by when it should be done, and also to ensure that it was done. The working party contained representatives not only of the gas turbine section but also of the ship design sections, the fleet maintenance directorate, the headquarters of the naval dockyards, the stores organization, the naval aviation headquarters and a naval aircraft repair yard.

The work of this group divided conveniently into three parts:

(*a*) to set up a naval facility for overhauling the gas turbine change units,

(*b*) to arrange the physical aspects of engine changing, transport, training, etc.,

(*c*) to set up a management organization for allocating and controlling the movement of engines between ships, overhaul facilities and stores so as to get the right engine to the right place at the right time.

Each of these will now be considered separately.

The decision to set up a naval overhaul facility for engine overhauls in addition to the one provided by the manufacturer was made to avoid the risks inherent in having all eggs in one basket. The depth of strip and the nature of the work carried out at the two will be identical, but flexibility is provided so that their relative loading can be adjusted:

(*a*) to take account of local priorities within each—on the one hand, commercial and, on the other, military priorities *vis-à-vis* the aero-engines of the three services.

(*b*) in case of fire damage or industrial unrest.

Arrangements for the physical changing of engines involved investigation and planning of, *inter alia*:

(*a*) special equipment for use in the ship, its storage on board or its portability and availability,

(*b*) the procedure for the change, and its publication,

(*c*) the documentation to accompany the engine,

(*d*) the type of people to do the change: How many? Where from? How transported? How trained? Where? With what facilities?

(*e*) the means of transporting the engines to an airport,

(*f*) the packaging of the engines for road transport and for flying,

(*g*) the type and number of aircraft needed to carry the engines, and the need for any special facilities,

(*h*) the setting to work and acceptance procedures for newly fitted engines.

Because their time is precious and their modification states diverse, the many hundreds of aero-engines clearly need a single controlling body. This must have the authority to select engines for particular duties and to initiate their movement to wherever they are needed, co-ordinating as necessary with the operational command of the fleet and calling on the engine change teams as required.

This organization, a small group known as the Gas Turbine Allocating Authority, requires two sorts of information to fulfil its task. First of all, it must continuously have adequate data about each of the engines it controls; principally this concerns the modification state, the hours run, and the number of engines at overhaul. Secondly, it must have timely receipt of sufficient facts about requirements for new engines to allow arrangements to be made for immediate supply of replacements and for unserviceable engines to be returned for overhaul or repair. To ensure that all this can happen smoothly and almost automatically, a series of standard format signals, returns, demands, etc. to be directed to standard addressees have been created. Ships are notoriously and very rightly resistant to new paper work and, for this and other reasons, the format of these signals, etc. has been made as nearly as possible the same as that for other equipments. The main differences will be in the way in which they are used at headquarters.

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