Paper read at the Royal Institution of Naval Architects on Tuesday, 8 April 1975

MACHINERY INSTALLATION IN THE TYPE 42 DESTROYER

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HMS Sheffield, the first of the Royal Navy's Type 42 destroyers completed her contractor's sea trials in August 1974. Main propulsion power for the Type 42 is provided by a combined gas or gas (COGOG) arrangement of Olympus and Tyne gas turbines driving two shafts fitted with controllable-pitch propellers.

This paper describes the development of the machinery installation of the Type 42 from the initial staff requirements to the completion of singularly successful contractors' sea trials. It discusses the basic and detailed design showing how the machinery package was developed, how use was made of modelling techniques and shore testing of the machinery. A review of the setting-to-work and sea trials period analysing the problems and snags encountered and showing how they were overcome follows.

Although an authoritative assessment of the design of the Type 42 destroyer would be premature at this stage, the paper concludes with a discussion of some of the more interesting design features of the machinery installation and its performance to date.

INTRODUCTION

It was in the Spring of 1967 that the decision was taken to fit the Type 42 destroyers with the COGOG arrangement. By the end of that year, a contract had been placed with Y-ARD for the production of Class Marine Engineering Specification and Guidance drawings. In the middle of 1968, tenders were invited for the first-of-class and by November of that year the order was placed on Vickers Shipbuilders Ltd.

By the middle of 1974, HMS *Sheffield* (Fig. 1), the first-of-class, sailed for her contractors' sea trials and five further Type 42 destroyers for the Royal Navy were in varying stages of completion in three different shipbuilding yards. Since acceptance, HMS *Sheffield* has been carrying out first-of-class machinery evaluation trials. Substantially the same propulsion plant was also adopted for the Vosper Thornycroft/Yarrow Type 21 frigate and the first of these, HMS *Amazon,* has been accepted by the Ministry of Defence.

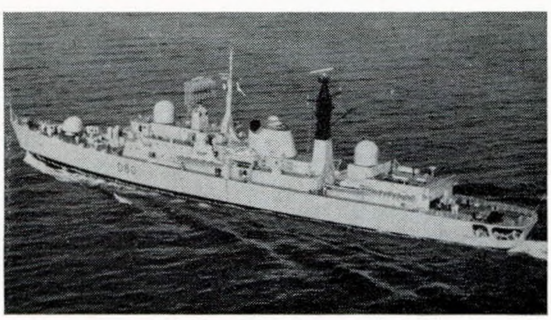

FIG. 1—*HMS* Sheffield

The purpose of this paper is to review the development of this COGOG plant from the deceptively simple concept envisaged in the early stages to the finished installation which is now at sea.

THE BASIC DESIGN

Background

Two years before the start of the design of the Type 42 destroyer, the Ministry of Defence, after considerable operational experience with the combined steam and gas turbine propulsion plants (COSAG) in the guided missile destroyers and general purpose frigates, had taken the policy decision that future destroyer propulsion would be by marinized aircraft gas turbines. At this time, approval was also given for the conversion of HMS *Exmouth,* a steam-driven frigate of the Blackwood Class, to all gas turbine propulsion. Machinery evaluation studies for the Type 42 destroyer accorded with this general policy and also with the specific ship requirements of:

a) an increased operational availability during the life of the ship compared to earlier designs—this was to be achieved by running for longer periods between refits with no extension in the length of refits;
b) minimizing the ship's complement—the manning costs being a most important factor in the through life cost of a warship, a significant reduction was required in the complement compared to earlier designs.

Development

Ship design studies carried out by the Ministry of Defence indicated that the Type 42 destroyers would displace about 3500 tonnes. Machinery evaluation studies for this displacement led to the choice of a twin shaft arrange-

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ment with one Olympus TM 3B gas turbine and one Tyne RM1A gas turbine on each shaft. At the higher ship speed the power would be provided by the Olympus and at cruising speeds, at which power levels the fuel consumption of the Olympus would be unacceptably high, the Tyne would be used, ie a COGOG installation.

Development of the basic design into detailed machinery specifications and guidance drawings was carried out by Y-ARD. From the outset, it was clear that the key factors in achieving increased operational availability were the reliability of systems and equipments, and an installation which provided for upkeep by exchange (U-by-E) of defective equipments or those due for major overhaul.

A substantial redundancy of vital equipments was required in order to meet the high degree of system reliability. All ancillary systems have redundant capacity such that following either the loss of a working unit, or the need to carry out planned maintenance, a full system capability can be retained; this applies also to diesel generators, distilling plants, auxiliary boilers, air-conditioning units and refrigeration plants.

A U-by-E policy necessitates standardization of equipments and major sub-assemblies so that replacements are, in practical terms, identical to the units being replaced.

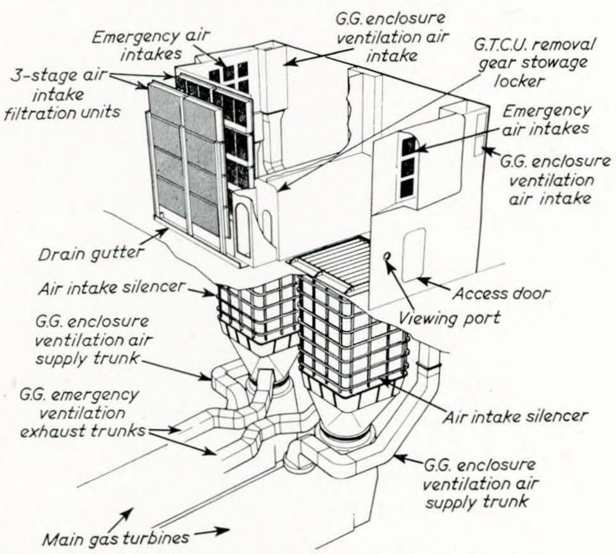

FIG. 2—*Main gas turbine air intake system*

In developing the basic Type 42 scheme, some of the more significant engineering aspects were:

a) *Means of Reversing*—As the gas turbines are unidirectional, the choice of a method of reversing lay between controllable pitch propellers (CPPs) and reversing gearboxes. Reversing gearboxes with fluid couplings were considered to be large, heavy and complex and reversing epicyclic gearboxes for the power involved were only in an early stage of development. CPPs on the other hand had been developed for power loadings not far short of those required for the Type 42 and it was felt that current designs could be safely extrapolated to meet the Type 42 requirements; CPPs were therefore selected.

b) *Fuel Handling and Air Intake System*—The performance and particularly the life between overhauls of gas turbines are sensitive to the quantity of salt ingested by the engine. The design objective has been to contain the salt in the fuel to 0·3 ppm of sodium by weight with a limit on the total equivalent sodium in both the air and fuel together of 0·6 ppm by weight. Typical air intake arrangements are shown in Fig. 2. Recognizing the affinity of Dieso for salt water, the purification arrangements include centrifuging, settling, filtration and water coalescing.

c) *Machinery Controls and Surveillance*—The controls are of the electric/electronic type and are compatible with the fast response of the machinery, the requirements for minimum engineering complement, low weight, space and ease of maintenance. Control and surveillance of the machinery is provided as follows:

i) Bridge—single lever control of each shaft set of machinery in respect of engine power and propeller pitch;

ii) Machinery Control Room—as for the bridge with the addition of starting, stopping and change-over of engines. Remote starting and stopping of vital motor-driven auxiliaries and diesel generators is also provided;

iii) Locally in Main Machinery Space—starting, stopping and throttle control of engines and control of propeller pitch. Local control of main machinery would only be employed in an emergency;

iv) Surveillance in Machinery Control Room—the number of gauges has been kept to a minimum and, in general only indicating gauges for 'driving' purposes are provided. A warning and annunciation system is provided in the MCR for monitoring the more important parameters of the plant.

d) *Simulation of Dynamic Performance*—A mathematical model was established for the ship and the propulsion machinery, and a comprehensive analogue computer study was carried out to establish and optimize gas turbine fuel-valve opening and closing times, propeller pitch stroking times, ship manoeuvring performance and torque, thrust and rotational speeds of the main machinery under a wide range of manoeuvring conditions. This was certainly the most comprehensive theoretical analysis carried out on dynamic performance for any surface warship of the Royal Navy.

e) *Gear Driven Auxiliaries*—Each shaft set of machinery has a lubricating oil pump, a CPP pump and a seawater circulating pump driven by the associated main gearing so that the propulsion machinery can in an emergency operate without electric power for a significant period of time; these pumps are capable of providing the propulsion services down to a low main shaft speed. Electrically driven auxiliaries are provided for use when starting up, for operation at low powers, and in case of failure of gear-driven pumps.

f) *Electric Generators*—Four diesel-driven generating sets are fitted. The choice of prime movers was straightforward; steam turbo-generators were not considered for obvious reasons and no suitable gas turbo-generator was available.

g) *Auxiliary Boilers*—Earlier studies for ships of similar size to the Type 42 had shown that low grade heat for ships' domestic systems and winterization was most economically provided by saturated steam; this could also be conveniently used for flash evaporators. An all electric ship was considered but this would have required an increase in the number of diesel generators of the size available.

To clarify the installation arrangement, extensive use was made of a 1/12-scale machinery model as a design aid. This model, as shown in Fig. 3, was passed to the shipbuilder at the start of the detailed design and build stage.

Fig. 4 shows a simplified plan view of the machinery arrangement which was arrived at from the following considerations:

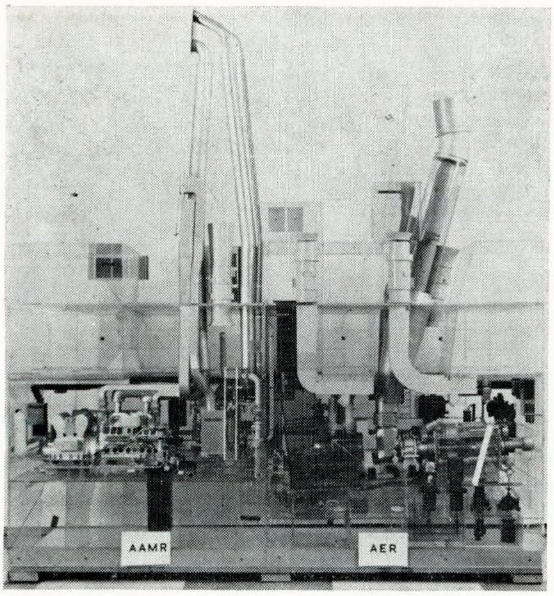

FIG. 3—*Y-ARD 1/12 scale machinery model*

on the ship design. The implementation of this upkeep policy requires not only large deckhead openings which must be kept clear but also a space allocation for machinery which by previous naval standards can be regarded as generous; this more generous space allocation follows naturally from the need to provide transportation routes within the machinery spaces to the vicinity of the deckhead openings. The removal and replacement arrangements for major plant items are shown in Fig. 5.

SURVEY OF SHORE TESTING

The Type 42 ship design and construction programme, as it evolved from the 1965 Defence Review, did not permit shore testing of the propulsion plant before fitting in a ship, as is Ministry of Defence policy for propulsion plants containing significant innovation. Fortunately, extensive testing of the Olympus TM3B and Tyne RM1A engines had already been programmed and it was known that the gearbox design could be contained within well proven practices and parameters. Furthermore, early in the design of the Type 42, a COGOG plant (one Olympus TM1 and two Proteus gas turbines) with a CPP and associated control system was operating at sea in *HMS Exmouth*.

The Olympus TM3B was installed in a test house at

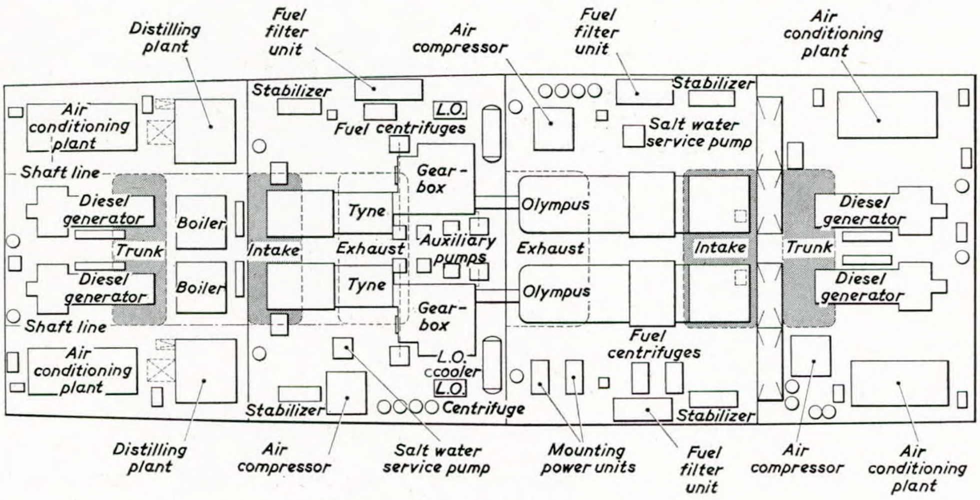

FIG. 4—*Machinery arrangement*

A) Putting the main and cruising gas turbines into separate rooms to cater for action damage;
B) widely separating the diesel generators, by locating them two in the forward auxiliary machinery room and two in the after auxiliary machinery room. Because of this wide separation no salvage generator is fitted;
C) widely separating the air conditioning plants;
D) putting the auxiliary boilers and distilling plant in a single machinery space. This, in association with diesel generators and air-conditioning plant, gives a grouping of hotel service plant which minimizes the manning requirements in harbour and facilitates maintenance;
E) locating the gas turbines, diesel generators and auxiliary boilers so that the associated combustion air downtakes and exhaust gas uptakes are within the centre third of the beam of the ship. This arrangement reduces the number of deckhead penetrations and is consistent with a single funnel;
F) distributing other auxiliary machinery among the four machinery spaces to decrease the effects of action damage;
G) providing space and facilities for removal and replacement of machinery in order to implement a U-by-E policy.

Of these, the latter (G) had perhaps the greatest effect

Rolls Royce in such a way as to give the maximum scope for trials of peripheral equipment as well as the actual engine itself. Several designs of uptakes were evaluated. The design problem was complicated in the Type 42 because the Olympus power turbine was fitted with accessible plain bearings which resulted in an exhaust volute with a large bite out of it to take the bearing pedestal. This gave a poor velocity profile at exit from the volute and the problems of back pressure, velocity distribution, expansion, noise and silencing have been varied and difficult[1]. Even when the gas had been conducted safely to the top of the funnel the problem was not over, for the proximity of the mainmast aerials required a detailed investigation into the rate of temperature decay of a gas plume under various wind conditions. The National Physical Laboratory played a vital part in this investigation and the programme of wind tunnel testing was spread over many months.

The engine module ventilation system was first found to be inadequate in the test house and the resulting modifications were tried and proved there. The behaviour of the Olympus high speed line input to the gearbox was studied as also were noise and smoke emission levels. The Tyne RM1A has been subjected to very much the same sort of programme, again with immensely valuable results.

More engine trials have been conducted at the Naval Marine Wing (NMW) of the National Gas Turbine Establishment, Pyestock, the accent here being on endur-

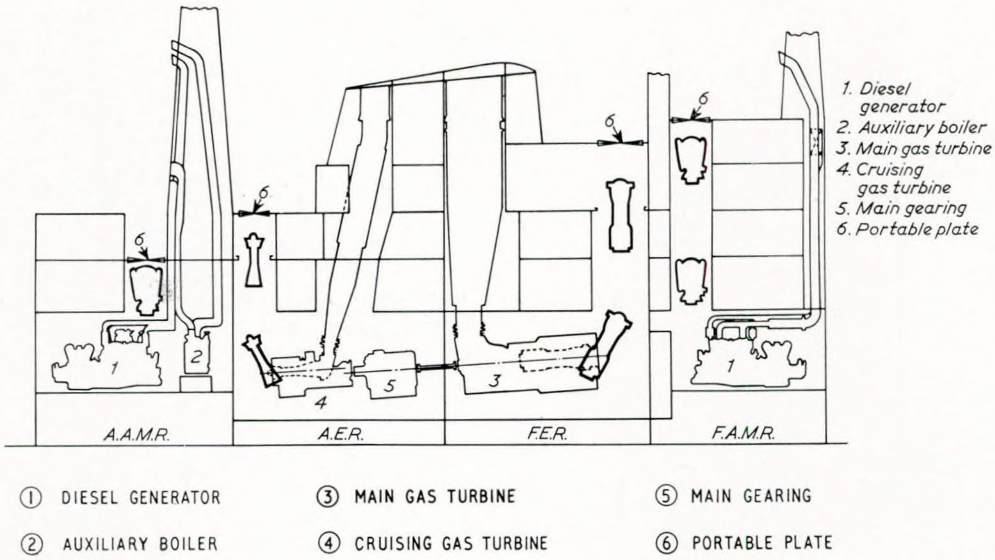

FIG. 5—*Removal—replacement arrangements*

ance running. NMW also carried out much valuable work on intake filtration and salt ingestion; as a result of this, the spray eliminators and filters now being fitted are much more efficient than the earlier design.

In other fields Y-ARD had done much theoretical study of the transmission lines at an early stage in the development of the design and this has since been supplemented by further analytical and practical work by David Brown Gear Industries and others. Shore testing of the gearboxes and the controllable pitch propeller systems was limited to shop floor functioning trials, where a number of potential problems were resolved. Computer simulations of the control system have been carried out by the Admiralty Engineering Laboratory and others. At *HMS Sultan* a training simulator has also proved useful and, although it is primarily intended for the training of would-be operators, it has highlighted a number of areas which needed modification and improvement.

The auxiliary machinery, including the boilers, distilling machinery, generators, pumps and air-conditioning machines, have all been subjected to full type-testing. These tests, designed as they were to prove not only the reliability and performance, but also the shock resistance, noise level and endurance of a machine, proved valuable in locating design deficiencies. Some of the trials were carried out at the manufacturers' works and more at the Admiralty Marine Engineering Establishment, Haslar.

DETAILED INSTALLATION DESIGN

In developing the machinery installation, model techniques were used instead of traditional drawing methods; the shipbuilders' model was built from coloured perspex and wood to 1/6th full size. This scale was selected as being large enough to give ± 10 mm accuracy on the ship and at the same time small enough for convenient handling by the modellers. Each machinery space was modelled in two halves, the split being longitudinally on the ship's centre line, and all systems of 25 mm diameter and larger were modelled. The completed model for part of the after engine room is shown in Fig. 6.

At various stages the models were inspected by the Ministry of Defence, particular attention being paid to the tidy arrangement of systems, operator ergonomics and access for maintenance of machinery, ship's plating and machinery seatings. Following these inspections and subsequent modifications, upkeep-by-exchange arrangements were demonstrated for complete equipments and major sub-assemblies. A product of the demonstrations is a set of written procedures, with supporting drawings, covering the removal routes of all equipment whose maintenance policy is upkeep-by-exchange. On final approval of the

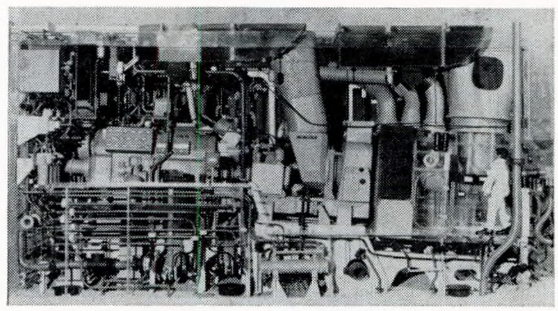

FIG. 6—*Aft engine room starboard 1/6th scale machinery model*

model, production and installation drawings were made by scaling from the model.

There is little doubt that the installation achieved through the use of model techniques is superior to that obtained by traditional drawing procedures particularly from the operation and maintenance aspects; to a large extent this is due to the ease with which physical arrangements can be appreciated from the model by the many parties involved. The model is useful also to the installation trades and at later stages is to be used for training naval personnel at HMS *Sultan*.

In detailing the installation, some areas of complexity and congestion inevitably arose; three particular aspects are:

1) The gas turbine installation, by its very concept, contains far more electrically driven ancillary and auxiliary machinery than traditional naval steam installations—the full extent of starters, junction boxes, change-over switches, system redundancy and cabling involved was not recognized at the outset;
2) provision for upkeep-by-exchange dictated that removal routes and the areas under removal trunks had to be kept clear, resulting in piping and electrical systems being longer and more tortuous than would otherwise have been the case;
3) the fitting of gear driven pumps for the lubricating oil, CPP and sea water systems entailed running these systems closer to the gearboxes than was otherwise required—this posed a relatively inflexible installation problem, which was not eased by the growth of the CPP system during development.

All these aspects contributed to the congestion in the after engine room, with implications on building and maintenance costs. Whilst some aspects of this nature are almost inevitable in a novel design, it emphasizes the need for a good measure of detailed installation design before "freezing" compartment sizes.

A novel feature introduced into the design was ventilation of the machinery spaces from a deckhead plenum chamber, instead of the more conventional trunked-air distribution. This arrangement has resulted in tidier machinery spaces and its efficiency has been demonstrated on trials; as a bonus it provides good noise attenuation. However, until extended service experience is gained, judgement of the deckhead plenum must remain open particularly in respect of the problems which could arise after removal and replacement of the lagged panels during upkeep-by-exchange operations.

To contain the fire hazard it was required that a "closed" vent and drain system be fitted to the fuel and hydraulic systems. This particular requirement developed into a general clean bilge policy whereby the vents and drains of all systems, including steam and water systems are led to sullage tanks. This policy not only enhances safety but improves the condition and appearance in the lower parts of the machinery spaces; it should also reduce the bilge and machinery seating preservation task.

In any naval vessel the installation programme is largely governed by pipework manufacture and installation. For HMS *Sheffield,* pipe isometrics were scaled from the machinery space and passageway models, and these were used to advance pipe production relative to the ship build programme. The model system further assists in reducing the overall programme as it enables production of the pipework isometrics at an early stage of the drawing programme, ie prior to general arrangement drawings. Many lessons have been learned and the resulting techniques for passing information to the manufacturing shops are contributing to overall greater efficiency in these areas.

Despite the growth in complexity during the detailing of the design the systems remain simpler than in a comparable steam installation and the overall improvement in the machinery space is beyond question.

INSTALLATION OF MACHINERY

Before shipping of the main propulsion and ancillary systems started detailed installation procedures were prepared for critical operations such as engine alignment and installation of the CPP system. During installation it was found that provided the procedures were followed and cleanliness standards maintained few novel problems arose. However a number of points are worthy of mention:

Shaft Installation and Alignment

The alignment of shafting in the Type 42 destroyers is complicated by the CPP shafting internals which preclude breaking of inboard couplings after launch, and by the flexibility of the shafts which makes their use for direct alignment difficult. Thus the principle involved is based on the alignment of bearings one to another before installation of the shafting. Final chocking of the gearboxes is completed after launch to eliminate the major effects of ship breakage in this sensitive area, the gearbox flange coupling is adjusted to an offset with the shaft forward end flange designed to optimize the static loads on the main wheel bearings.

In HMS *Sheffield* the procedure was upset by a serious explosion at the after end of the ship some two months before launch, when shafting alignment was complete. Repair of the consequent damage entailed replacement of a complete section of the vessel, 7·62 m in length and extending up to the main deck. The vessel was therefore launched without the outboard shafting and with the 'A' bracket alignment uncertain.

To avoid delays to the gas turbine installation programme, it was necessary to finalize the gearbox alignment prior to docking for re-boring the 'A' brackets and installation of the tailshafts. Dummy loads were applied to the ship and to the inboard shafting to simulate the complete shaft line. Theodolite sightings were taken to establish the ship's breakage which was later reproduced by adjusting shores when the ship docked (Fig.7). The shafting line-of-sight was then re-established from the inboard bearings, the 'A' brackets re-bored and the shafting completed. HMS *Sheffield* is therefore unusual in that her shafting alignment was made to her true waterborne line-of-sight.

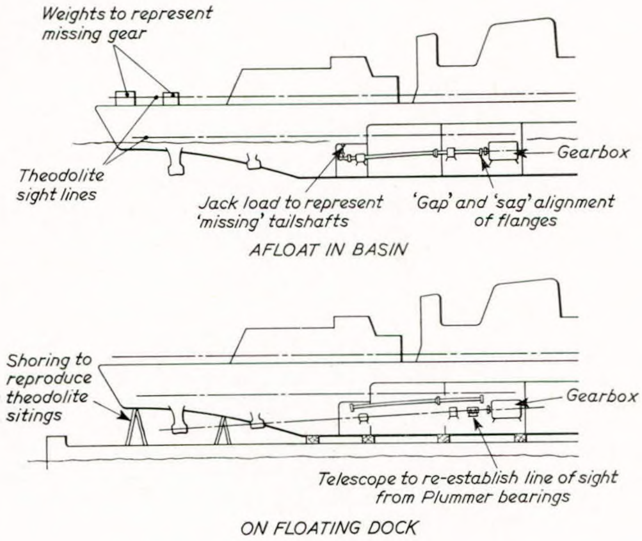

FIG. 7—*Shaft alignment problem*

Alignments were found to be greatly influenced both by ambient variations and by local loadings. On the other hand the shafting, in keeping with naval policy, is very flexible and the effects on bearing loads of quite large bearing displacements, particularly at the after end of the ship, can be small. Some relationships however remain critical and judgement is required to ensure proper attention and care in the right areas without needlessly incurring considerable expense in the remainder. It is unlikely that drawing tolerance and written procedures alone can provide a complete answer; the skilled tradesman has much to contribute, and a close liaison between designer and "man-on-the-job" is essential.

Allied problems were those associated with fitting the CPP system oil transfer tubes into the shafting and installation of the propellers and forward oil transfer boxes. This work comprises a sequence of operations completed in dock after launch. The procedure is lengthy (about 12 weeks docking required) and is complicated by the need to maintain clean conditions throughout and to pressure test and flush the hydraulic system at each stage. In future installations consideration will be given to designing for complete assembly of shaft internals prior to installation of the shafting in the ship.

Pipework Installation

In HMS *Sheffield* the arrangement of pipework associated with the CPP propeller hydraulic system was complex and congested; consequently a rather unusual procedure has been developed for follow-on ships. A mock-up of the surrounding area has been constructed in the pipe productions shop and a complete pipework system for each ship is being fabricated and erected in the mock-up. On completion, the system will be removed to the ship, re-erected, and adjoining tanks, etc., will subsequently be positioned to suit the pipework. This is contrary to the conventional procedure where make up pieces are used to adjust pipework to meet equipments.

Engine Installation

The gas turbine change units (GTCUs) are required in the ship at a fairly early stage when, by definition, the ship is still not in a satisfactory state to accept these relatively vulnerable units which need regular protective maintenance. This problem was neatly solved by the use of gas generator "weight and space" models, built in glass fibre to realistic external detail, which enabled completion of the weight sensitive mounting systems, alignment of engine intake bends and proving of engine removal routes without risking GTCUs.

SETTING TO WORK AND SEA TRIALS

Organization

The Ministry of Defence requires warship builders to set up a Dockside Test Organization for testing, setting to work and trials of ship and machinery systems. The heart of the organization is the Test Group, which comprises representatives of the Shipbuilder, the Principal Naval Overseer and the Commanding Officer of the ship; this group is responsible for the authorization of the test forms used for system testing and basin trials, and certification that tests and trials have been carried out satisfactorily.

The extent of the testing programme up to basin trials may be judged from the fact that at the peak of the testing programme some 35 engineers were engaged in commissioning the ship and propulsion systems.

The overall conduct of the machinery sea trials was vested in a Sea Propulsion Test Group jointly headed by the officer-in-charge of the Ministry of Defence's Machinery Trials Unit and the Shipbuilder's Commissioning Manager. Throughout the trials the machinery was operated by the shipbuilder's personnel with, for training purposes, nominated members of the ship's company.

Commissioning Period

The commissioning period extended from the spring of 1973 to early summer 1974. During this period the auxiliary machinery and main propulsion and ancillary systems were set to work. As might be expected with a first of class containing many new or modified systems and equipments, setting to work revealed various design deficiencies and interface problems. However, none of these could be considered major problems and most were readily resolved.

Commissioning of HMS *Sheffield*'s main propulsion system was, in the event, overshadowed by the experience gained in HMS *Amazon*'s contractors' sea trials during the latter part of 1973. These trials revealed deficiencies in four key areas of the propulsion plant:

i) The accommodation of the gas turbine modules and downtake and uptake trunking introduced the requirement for 'long' torque tubes between the turbine and gearboxes. This is a very difficult design area for which a wholly satisfactory analysis has yet to be developed. In HMS*Amazon*, vibration levels in the Olympus high-speed line were in excess of acceptable limits and it was decided to replace the initial design of torque tubes. As a result of this experience a detailed reassessment was made of the arrangements in HMS *Sheffield* in which, with the exception of shorter torque tubes (203 cm in lieu of 239 cm), the lines are identical. It was concluded that, given good alignment and balance of the lines, problems in HMS *Sheffield* were unlikely, and indeed this has proved to be the case.

ii) The modifications necessary in HMS *Amazon* to the primary reduction pinion bearings to contain bearing temperatures at full-power speed and to the primary gearwheel thrust bearings to increase their load carrying capacity during power transients equally applied to HMS *Sheffield*.

iii) Various modifications were required in HMS *Amazon* to the machinery control console to improve reliability and maintainability, and to overcome other problem areas which emerged as a result of the system earthing arrangements. Some logic changes were also required; for example, during change-over from the Tyne to Olympus engines, it was found that the power of the Olympus engine was increasing before the Tyne clutch had fully disengaged which resulted in the Tyne being overspeeded. Resequencing of the change-over operation provided the solution.

iv) In the CPP system, the principal problem occurred in the control of the propeller pitch; the dead band of the hydraulic system was too great and resulted in inaccurate and unstable control. The sensitivity of the system was improved by modifications to the hydraulic system although these regrettably introduced more valves and pipework to an already complex arrangement. During this period, problems were also being experienced with the control of the CPP pump swash plates in HMS *Sheffield*. Resolution of this problem required adjustment to the pump internal clearances and the provision of an increased swash-plate servo pressure.

While these essential modifications to the main machinery were being carried out in HMS *Sheffield*, the opportunity was taken to incorporate an improved design of water collection and drainage of the gas turbine air intake filters. Refinements were also made to the steering gear control system to improve reliability and accuracy.

Basin Trials

The benefits derived from these improvements led to a relatively trouble-free official basin trial at the end of March 1974. The main items arising were:

a) The idling speeds of the Olympus engines were found to be inconsistent; too high an idling setting tending to give a hot start and too low a setting resulted in a loss of remote control. A modification to the fuel system—a fuel pressurizing valve in lieu of a distributor—has been proved and will be fitted.

b) Occasional high levels of vibration occurred in the Tyne engines when starting on cold oil. This has also been found in the test bed engines so far however, without ill effects, and no immediate action is contemplated.

c) Even at the low shaft speeds used on basin trials, shaft plummer bearing seals run hot. These seals were fitted to prevent ingress of water to the bearing under damage conditions. The strength of the backing spring was reduced and clearances and loadings of the seals were adjusted with complete success in later trials.

Contractors' Sea Trials

HMS *Sheffield* sailed for contractors' sea trials on 30 June 1974 and these totalled 27 days at sea.

Before proceeding to sea, the ship-fitted dynamic data recording (DDR) system was extended by the fitting of additional sensors and recorders for monitoring the performance of the machinery control system and the CPP system. Additional surveillance and recording equipment was also fitted for trials of the steering gear system, stabilizers, the Olympus constant position mounting system, and the measurement of machinery vibration levels. Arrangements were also made to record all the machinery control system parameters for comparison with the earlier computerized dynamic simulation.

An inherent characteristic of gas turbine ships fitted with CPPs is that adjustment and proving of the control system settings at, or close to, full power is an essential prerequisite to any worthwhile trials at low power. The sequence followed was to set full power pitch, adjust the on-engine controls and finally calibrate the off-engine control schedules. Subsequent engine changes should require adjustment of the on-engine controls only. The achievement of full power after only 30 hours at sea was most encouraging; this condition was cautiously approached to avoid overtorquing or overspeeding of the machinery.

Having proved the control system settings at full power, the trials of the main propulsion units, auxiliary machinery and steering gear were progressed. This range of trials was far less eventful than one might have reasonably expected considering the novelty of the propulsion plant. A notable feature was the ease of control of the propulsion plant and auxiliary machinery, and the relative ease with which the machinery operators handled a plant with a very quick rate of response compared to the traditional steam plant. The confidence of the operators well demonstrated the value of training on the machinery simulator at HMS *Sultan*. However, layout of the machinery control console was criticized and it was generally considered that a mirror image layout of the Tyne and Olympus port and starboard control panels would be preferable.

Manoeuvring trials were exciting and the DDR system provided a wealth of data. Points of particular interest were:

i) During some high-power ahead-to-astern manoeuvres, the speed of the propeller shafts dipped momentarily below the speed at which the gear driven pumps maintain minimum lubricating oil and CP system conditions. The response rate of the automatically started motor-driven auxiliaries averted the occurrence of any potentially dangerous machinery conditions.

ii) Initial simulation studies of ship manoeuvring suggested that an Olympus acceleration time of 13 seconds from idling speed to full speed would be required for acceptable ship low-speed manoeuvring. It was found during sea trials that this acceleration imposed unacceptable transient conditions upon the machinery; subsequently an increase in the time to 30 seconds from idling speed to full speed obviated these unacceptable transients with no measurable detriment to ship manoeuvring performance at any power.

iii) Comparison of the Tyne and Olympus stopping manoeuvres from similar powers showed that the slower rate of change of propeller pitch associated with the Tyne engine (1·3 degrees per second opposed to 3·3 degrees per second for the Olympus) enhanced the ship manoeuvring performance.

As a result of this trial experience and the data acquired, a range of ship manoeuvres are being re-examined using the simulation model.

The trials period was proceeding with commendable success until the penultimate day when a bearing oil scavenge pump failed on the starboard Olympus engine gas generator. Although a spare pump was fitted, proper bearing scavenging was not realized and the need for a gas generator change could not be eliminated. At this stage, only the six hour full-power trial remained outstanding. Since some 20 hours' full-power running had already been accumulated and confidence in the machinery at this power was high, it was decided to include this full power trial in the final machinery trials rather than cause delay to ship acceptance.

Thus HMS *Sheffield* returned from her contractors' sea trials having carried out a demanding trials programme with great success; the only noteworthy problems were:

a) The motor-driven CPP pump servo was prone to drift from the zero position when in the stand-by condition, so preventing the pump being started. This was overcome by fitting additional non-return valves to hydraulically lock the servo system.

b) A slight hunt remained in the starboard CPP system. It is believed that this should be obviated by the fitting of CPP pumps with modified swashplate trunion bearings, but the possibility remains that this hunt could be a product of the separate or combined response of the electric and hydraulic control systems.

c) Hydraulic aspects of the constant position mounting system under the Olympus engines gave cause for concern due to drain line pressure fluctuations manifesting themselves in the form of valve shock chamber compressions. Preloading of the valve springs would appear to provide the solution.

d) Two failures of the machinery control system occurred, both of which were readily diagnosed and quickly rectified. However, one failure caused the rapid achievement of full astern pitch and this raised the question of whether the fail safe mode is totally stable under all circumstances. This is being investigated in the simulation model.

e) The failure of the second Olympus scavenge pump was subsequently shown to be operator error; in the haste to fit it and restart the engine, it was inadequately primed. An engine change was not required.

Leaking valves in the fuel stripping system and a leaking sea tube gave rise to excessive sea water in the fuel system. This occurrence provided an unscheduled and demanding test of the fuel treatment system. Laboratory tests of samples taken from the system showed a maximum sodium content of 0·3 ppm by weight, which is within the design objectives.

Opening up the machinery for inspection subsequent to sea trials has not revealed any design deficiencies or signs of distress other than flaking of the nickel plating applied to the main shafts in way of the plummer bearings and bulkhead glands. The obvious solution—removal of the coating—has been applied.

During the machinery opening-up period it was also successfully demonstrated that the Olympus and Tyne GTCUs could be removed and replaced as planned and within the specified time-scale.

Since acceptance HMS *Sheffield* has been carrying out first-of-class machinery evaluation trials. These trials are primarily aimed at:

i) gaining experience of teething troubles in the machinery and proving that the machinery is capable of satisfactory operation by naval personnel under service conditions and in extremes of climate, both tropical and arctic.

ii) determining the best machinery operating techniques so that proper instructions can be provided;

iii) providing maintenance information for the validation of maintenance schedules and ship operating and maintenance cycles;

iv) providing the designers with detailed information on the performance of the plant to enable the design to be checked, and to apply the lessons learned to the future.

COMMENTS

The Royal Navy's experience of the Type 42 destroyer machinery is, as yet, essentially confined to the design, construction, commissioning and sea trials, and any attempt at an authoritative assessment of the design would be premature, particularly of those features which require evaluation through extended operational service. However this experience when reviewed together with the 18 months' sea experience of HMS *Amazon*, seven years' running of the COGOG installation in HMS *Exmouth*, and many years of in-service experience of the COSAG plants in 16 general purpose frigates and guided missile destroyers does provide many factors worthy of discussion.

Gas Turbines and Peripheral Systems

Gas turbines, being at the heart of the COGOG installation, deserve first comment. Lieut.-Commander R. M. Lutje-Schipholt RNN in his recent paper[1] ranges the problems encountered in the marinization of the Olympus and Tyne gas turbines and further discussion on this aspect is unwarranted. The products of the development programmes are now at sea and in-service experience, albeit limited, has been most encouraging. For example the last Olympus gas generator removed from HMS *Exmouth* for inspection had run for 3100 hours, and the inspection revealed the engine to be in excellent condition with potentially many running hours of life remaining. There are, of course, several aspects of engine development which are continuing and which should result in a progressively extended engine life. These currently include:

a) combustion chambers—to improve life and to obtain clearer exhaust emissions;
b) compressor and turbine blading — to improve materials and coatings and to combat corrosion;
c) fuel pumps—to improve tolerance to low lubricity fuels.

The need to supply the gas turbines with air of low salt content has been referred to earlier. Extensive trials and development have led to the adoption by the Royal Navy of a three stage air inlet filter for future ships. All evidence is that these filters will meet the specified minimum salt ingestion limits over the whole power range of the engine and under all weather conditions. However, even though the specified levels were set from laboratory and engine testing, extended in-service evidence is required to establish that the levels are correct; it could be that unnecessarily demanding standards have been set and any simplification and weight reduction which might be realized by using a less sophisticated filter would be most welcome to ship designers. Whatever levels are adopted and whatever system of filtration is fitted, it is clear that much greater attention to the detailed design of air velocity, distribution and drainage arrangements is required than was necessary for boiler air intake systems.

A well-debated subject has been that of the materials to be used for gas turbine uptake systems. In the Type 42 destroyers, stainless steel was selected whereas aluminium-sprayed mild steel has been fitted in the Type 21 frigates. The results of in-service experience are eagerly awaited; will the adaptability of the traditional steam ship funnel material prove to be better in the long run than the relatively high-cost alternative with all its manufacturing problems and claimed advantages? Further study in this area may yet yield significant cost savings.

The adoption of all-gas-turbine propelled ships has been consistent with the Royal Navy's single fuel policy. Dieso is used for gas turbines, diesel engines and auxiliary boilers, and this simplifies the fuel system. However, in the Type 42 ships for stability reasons about half the ship's fuel is stowed in sea water displaced fuel tanks. In deference to the sufferings of bare mild steel in the presence of Dieso and sea water, the tanks have been coated with epoxy paint. All main fuel tanks in the ship have been treated this way, and it is another area where a valuable long-term comparison can be made with HMS *Amazon* which has bare tanks.

As a result of the development programme, it is felt that the majority of the peripheral system problems are now reasonably understood and, if not entirely solved, there are none which impose any notable limitations on the operation of the propulsion machinery in HMS *Sheffield*.

The CPP System

A closed-loop hydraulic system, utilizing variable-displacement swash plate pumps was adopted primarily to conserve power in dormant periods and to afford better control over propeller regenerative forces, ie during ahead-to-astern manoeuvres[2]. The development of the system from concept (Fig. 8) to a ship's system (Fig. 9) has led to complexity of pipework, to a need for very high standards of system cleanliness, to oil viscosity limitations and to complications of control. Control of propeller pitch involves controlling the output both of motor-driven and or gear-driven pumps, the output of the latter being a function of the shaft speed as well as swash plate angle. The control-loop is normally closed by the machinery control system, but in the manual control mode the operator is an actual part of the loop and has a "variable" rate control system with which to deal. Surprisingly, it was demonstrated during sea trials that manual control in a steady state is fairly easy.

At the initiation of the design, knowledge of controllable-pitch propeller transient dynamics was somewhat sparse and it is not surprising therefore that "provision for the unknown" has led to overdesign of hydraulic pressures and flow rates and as a consequence oversized piping, coolers, cooling water and electrical supplies.

Despite its complexity, it was shown during sea trials that the CPP system satisfies all its functional requirements. However, in the light of data now available, it is believed that the requirements could be satisfied by a much simpler and lower capacity open-loop system using a single control valve in each system. The objective to conserve power in dormant periods has been partly offset by the relatively high and continuous power required by the boost pump.

Machinery Controls

The machinery control system, which co-ordinates principally the engine throttle and propeller pitch movements, suffered many delays during commissioning. This was largely due to repeated modifications in the wake of experience in HMS *Amazon,* where it was apparent that the control system requirements had not been stated with the precision that is necessary for a system not provided with facilities for "screwdriver" adjustment. With the experience now to hand, better specification of control system requirements should be possible in the future; development of ship and machinery simulation techniques through the correlation of trial results should also help considerably.

The dynamic data recording equipment has demonstrated its value during setting to work and trials of the machinery. Regular in-service recording will also show any fall-off in the performance of the machinery. In association with a loop tape-recorder, the equipment provides for effective panel diagnosis. A typical trace taken during manoeuvring trials is shown in Fig. 10.

Electrical Power Generation

A consequence of the change from steam to gas turbine propulsion was the replacement of the highly flexible steam turbo-alternator by the diesel-alternator with its constraints on loading if acceptable overhaul intervals are to be achieved. However, in medium sized warships with large electrical demands by weapons and air-conditioning plants, the range between the maximum load, such as under action conditions in the tropics, and the minimum, as obtained during cruising at night in temperate waters, is very wide. This brings the need, if diesel alternators are to be fitted, for precision in estimating electrical loads and the subsequent careful selection of both the size and number of alternators to be fitted.

The Installation

Compared to a steam plant, the Type 42 gas turbine installation, including gearboxes, transmission systems, downtakes, uptakes and auxiliary machinery is 15 per cent lighter and takes up the same space[3].

The benefits of using models as an integral part of the design process are very evident from both operation and maintenance viewpoints. However, primarily because of system or equipment growth during development, some

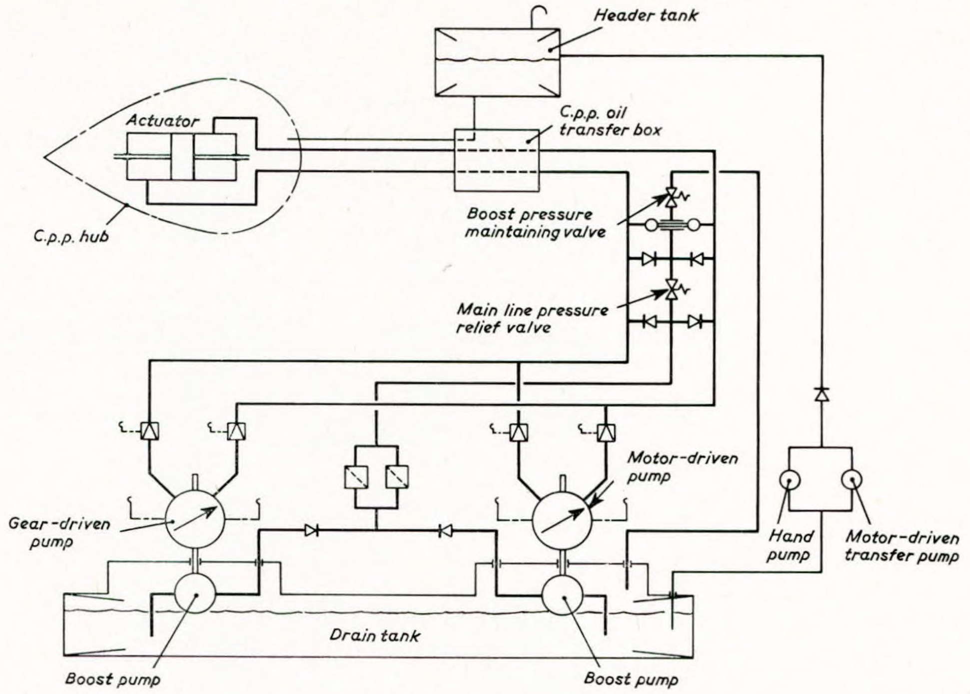

FIG. 8—*The C.P.P. system—Initial concept*

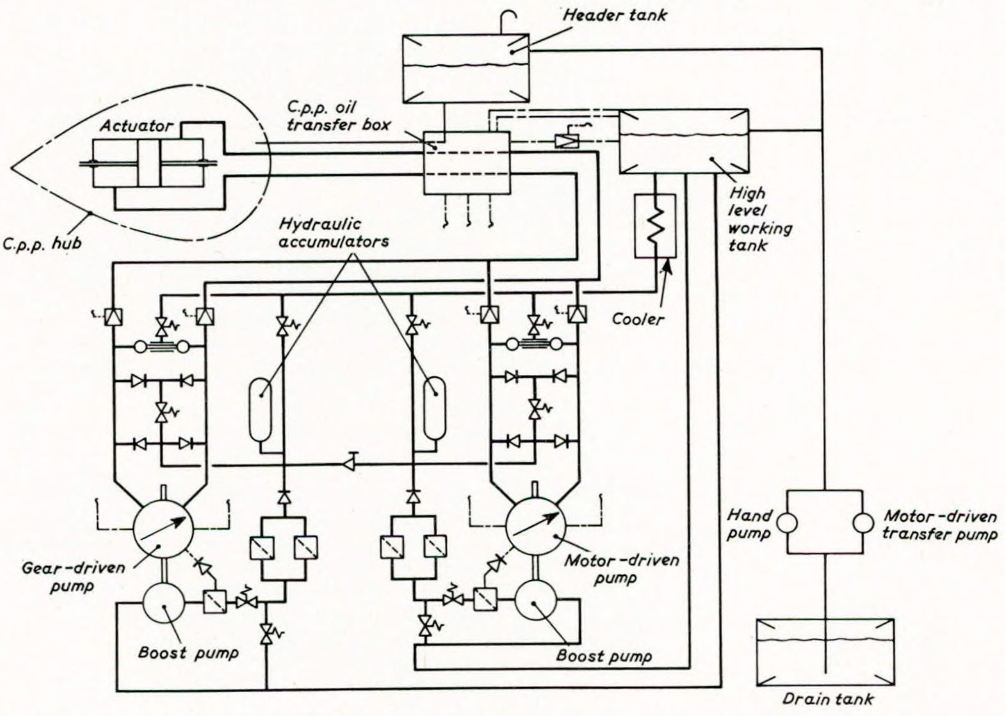

FIG. 9—*The C.P.P. hydraulic oil system—Final installation*

areas are less accessible than envisaged at the modelling stage. The full facilities for upkeep by exchange of ancillary and auxiliary machinery will only be proven by in-service experience; in the few cases where a change of machinery has been required, the task was readily accomplished as planned in the models. The policy in designing the removal routes was that they were not to be encroached upon in any way. Whereas this policy ensured facilities for upkeep-by-exchange, it has to be admitted that it does take up a lot of space. With hindsight, it is apparent that at least some of the space can be effectively utilized without impeding upkeep-by-exchange as exampled by the late fitting of a portable store in the after auxiliary machinery space diesel removal route trunking of HMS *Sheffield*.

Complement

The engineering department complement in the Type 42 is a 35 per cent reduction on the number which would have been required for a steam installation. Although only extended in-service experience will show if this initial complement is sufficient, the savings in ship through-life costs must remain significant even if minor adjustment should prove necessary.

The conditions in which the engineering personnel work are perhaps as important as the reduction in comple-

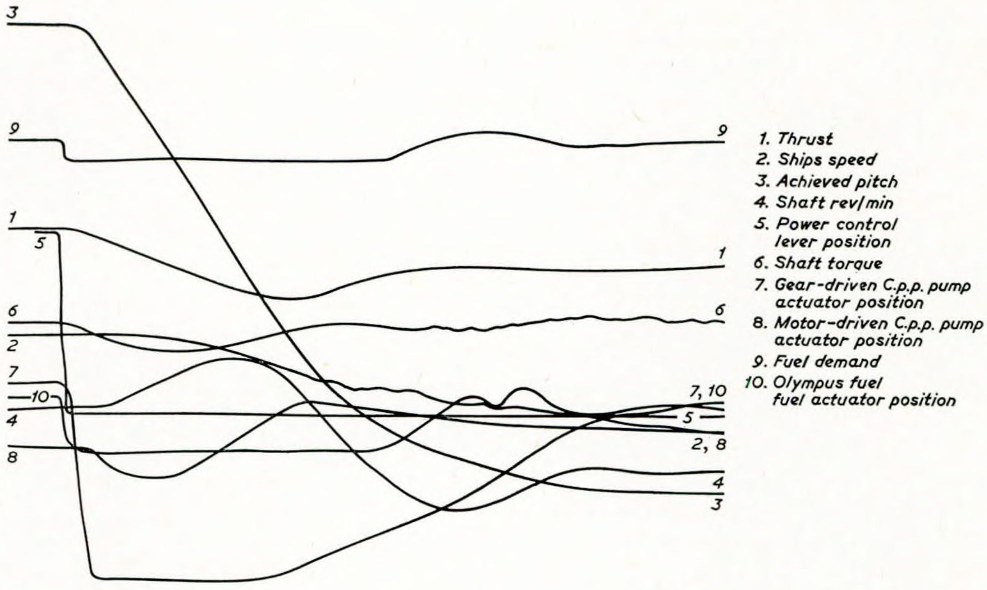

FIG. 10—*Ship performance DDR trace Port system—40 per cent ahead to 40 per cent astern*

ment. The history of steam is one of operating and maintaining machinery under generally hot, oily and unpleasant conditions whereas the environment in which the artificers and mechanics of gas turbine driven ships are employed are far more agreeable.

Fuel Consumption

In taking the decision to adopt all-gas turbine propulsion, no claims were made for potential fuel economy. Indeed at that time, consideration of marginal differences in fuel consumption between gas turbines and steam installations were secondary to such factors as increased availability and reduction in complements (for a warship, fuel costs were then of the order of $1\frac{1}{2}$ per cent of the through-life cost). However, by the time HMS *Sheffield* was completing construction, fuel costs had risen fourfold and fuel consumption had assumed greater importance.

Fig. 11 compares the specific fuel consumption of the Olympus-Tyne COGOG plant (as measured on trials) with the Leander Class frigates, the last Royal Navy design of all-steam frigates. The fuel economy to be gained from single-shaft operation of the COGOG plant will be readily apparent; this mode of operation in a Leander gives no gain in economy. Single-shaft operation of the plant will also give a substantial reduction in engine running hours, thus saving engine changes and subsequent overhauls, and enhancing ship availability.

CONCLUSION

The development of the Type 42 destroyer COGOG installation is a stride in marine engineering technology comparable to the change from the fire-tube boiler and reciprocating engine to the water-tube boiler and steam turbine. Despite the novelty of the concept and the complexity of some parts of the system and even though development in many areas ran well into the construction

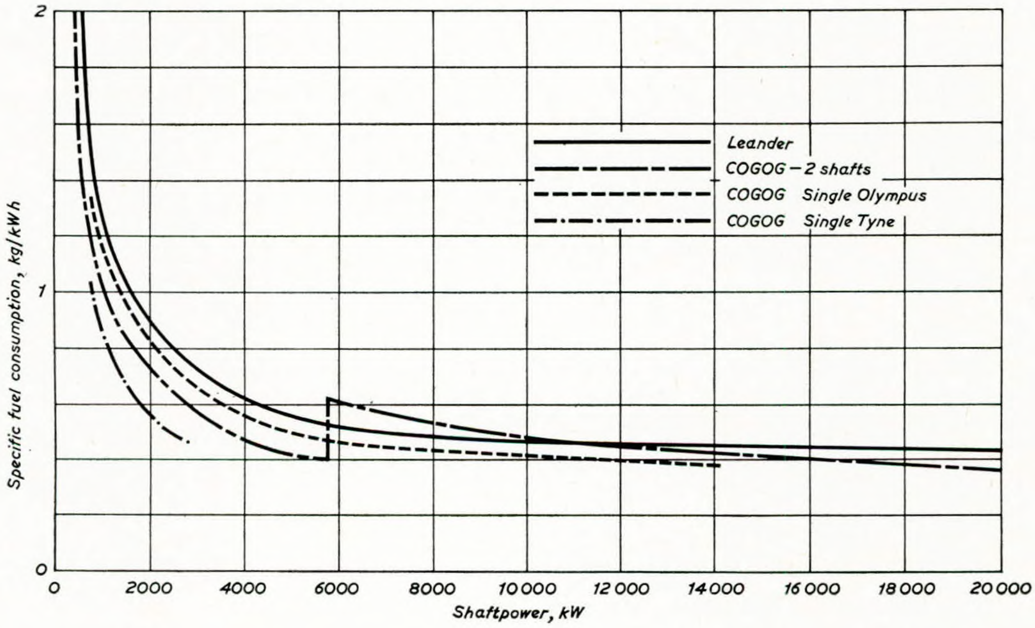

FIG. 11—*Comparison of specific fuel consumption—Leander class frigates and Tyne-Olympus COGOG ships*

period, HMS *Sheffield* completed her contractors' sea trials impressively quickly and with few real problems. Many of the design objectives have already been successfully demonstrated and there is high confidence that in-service expectations will be achieved.

The Royal Navy now has three COGOG-propelled ships—HM ships *Exmouth, Amazon and Sheffield*—in service and the collective evidence is that the bold decision to adopt marinized aero gas turbine propulsion for future surface warships of the Royal Navy was indeed sound and far-sighted.

ACKNOWLEDGEMENTS

Whilst this paper is published with the permission of the Ministry of Defence the views and opinions expressed are those of the authors and do not necessarily represent those of the Ministry of Defence. The advice, help, and suggestions from members of the staffs of Vickers Shipbuilders Limited, Y-ARD and Director General Ships are gratefully acknowledged.

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Discussion

CAPTAIN P. SLIJP, R.Nl.N., congratulated the *troika* of the designer, the shipbuilder and the customer for producing the paper.

The Netherlands M.O.D. had come to the conclusion that manning such ships and also operational availability in the 1970's and 1980's would be a problem. In Holland it was very difficult to get volunteers to become engineers in the Navy, so they were pleased to build ships which required 25 engineers instead of 40.

Operational availability now was obtained through module repair, and refits should take less time than in the past. For the same reason the choice of marinized gas turbines was, from the operational side in the Netherlands Navy, the best—apart from commercial considerations.

The COGOG principle was no problem in Holland at the moment. Two ships were being built and they had started with a contract with Y-ARD for a machinery specification which had been more or less based on the Type 42. The engine room layout was similar; the main propulsion was the same, and they would keep it that way.

When the Netherlands started to build *Tromp* the same propulsion plant as that described in the paper had been used, but this had been taken a little further by using completely electronic controls with push buttons as this was possible with gas turbines and solved the problem of people having to think at the controls. *Tromp* was now carrying out 10 days of contractor's sea trials and on the first day one of the executive officers had pressed a button too hard and broken it. Unfortunately, the designers had not realized that some people had such strong fingers. This difficulty had been overcome by taking another part from the console and putting it on the bridge, and within half an hour the ship had sailed. One of the requirements of the specification was that every fault in the control system should be handled within half an hour.

The controls were of a Dutch design and built completely by a Dutch firm; he was confident that they would do the job well.

The differences in the other systems were not so great. The Netherlands Navy and also the shipyard had learnt much by carrying out a shore test, especailly about the design. The men could also be "familiarized" long before going to sea as was done on the gas turbine propulsion. They had had to work with the same mechanics as those in the *Leander* class frigate. The crew had been shown the new equipment and their reaction had been very positive in regard to "the friendly environmental mechanical machinery installation".

The shore test had been finished a year ago. *Tromp* went to sea in the middle of March 1975, and within a few days of this meeting would go on her acceptance trials for about two months. Captain Slijp hoped she would not hit the headlines in the daily press but would perhaps be the subject of a technical paper.

The Netherlands Navy had discovered that dynamic simulation was very important when dealing with firms who supplied the controls, and also that the computer people should know what could happen at sea before actually going to sea with the ships.

The technical centre of *Tromp* was completely different from that of H.M.S. *Sheffield*. The electrical, the propulsion and the N.B.C.D. mechanics had all been brought together under the control of the chief engineer, who was an engine room artificer. In the Dutch Navy the chief engineer was also responsible for all the electrics, all of which were completely automated in Dutch ships. An A.D.S. system was then a necessity for such a ship. It was a pity that there were gas turbine ships with steam boilers still operating for "hotel services", and with diesel engines for the electrics. It was to be hoped that in the future they would be able to do without the steam.

The push button system could start up the engine and also allowed control to the actuators, so apart from the control system bringing in the control as memory, it was possible to operate the push button by hand. One man overlooked the electrical part and the whole system could be run by five people, three sitting in chairs and two doing the occasional rounds in the engine room.

The control system was completely made in modules. The Netherlands Navy had taken a complete control system and had cut it in pieces and had said to the manufacturer: "We must be able to exchange the different parts from one position to another", and this had been achieved. On the starter controls small lamps indicated whether everything was working and doing the right thing. If it was not working properly flickering lights showed which system was at fault, and spare parts could be immediately used for replacements. All of the work involved was done by mechanical engineers. The systems were completely sealed as the Navy did not like to repair these electronics on board ship, preferring to use the spares, which were racked in readiness. The next series of "S" class destroyers would have the same system.

He asked the authors how they measured the p.p.m. salt content in the intake air to the gas turbine. He also asked if they could elaborate a little more on the optimization of this machinery plant as this would be installed in the Type 22.

Tromp had successfully made more than 600 h per gas turbine and in May 1975 would be on her way south for a six week period of testing of main propulsion and air conditions under tropical conditions.

VICE-ADMIRAL SIR GEORGE RAPER, K.C.B., F.I.MAR.E., said that since the building of the ship and her trials had outlasted his responsibility as D.G. Ships he had not had an opportunity before of thanking the many people who had contributed to the success of the Type 42. It had been a characteristic of many decisions taken in the past that sufficient money had not subsequently been spent on development to make them successful. The tendency had been to congratulate oneself on taking the right decisions and to leave it to the mechanics and artificers in ships to make it all come right eventually after many years of development testing at sea. In this case, due to the very good teamwork exemplified by the authors of the paper, a vast number of people had worked to bring about a successful outcome, and deserved an enormous amount of credit for it.

The paper could not really give the impression of the difficulties which attended the whole contract, for the contractor and for the M.O.D. The contract had been placed at a very early stage in the development of the design because of the importance of public relations with the Fleet and with the public after the 1965 Defence Review. This was when the policy statement was made that carriers were going to be phased out, and a great deal of emotion had been generated, so very great importance was put in placing the contract for the *Sheffield* as early as possible. As a result, a lot of the systems at that time had not been wholly defined, nor had the relative responsibilities between the M.O.D., the shipbuilder, Y-ARD, and so on, for their further development. It was some time since the design and installation of an entirely new and different set of machinery for warships had been attempted. At the same time the Ship Department of the M.O.D. had tried very hard to satisfy requirements for numerate estimates of reliability and a number of system evaluations for which methodology had been developed by the aerospace industry. So there had been a number of new policies about design methods and about documentation and for the upkeep which those involved must have had a most tremendous struggle to get right as well as getting the engineering right. They were to be warmly congratulated on their achievement.

There had also been great emphasis on the limitation of the price of the ships under the contract. It might seem a trivial point but the word "redundancy" used about the components of systems by the authors of the paper had caused some real difficulties for the designers. The Board of Admiralty had said: "If you have redundant machinery, get rid of it; this is being built to a price". So the Ships Department had had to avoid the use of the word "redundancy" and had used "maintenance margin" to express what was needed.

This was just an example of how careful engineers should be in the use of terms whose significance was defined and clear to them as engineering terms, but which could be a real stumbling block in public relations if they were used as ordinary words without qualifications when dealing with laymen to whom their engineering sense was not clear.

MR. R. F. RIMMER, F.I.MAR.E., thought that no one would disagree with the authors' conclusion that the development of the Type 42 COGOG machinery installation represented a significant stride in marine engineering technology. This stride had been accompanied by other important factors such as "Upkeep by Exchange" policies, new concepts in machinery control technology and a new generation of weapons. The result of these and other factors was evident in the very different appearance of H.M.S. *Sheffield* from that of H.M.S. *Ariadne* (see Fig. 12), the last Royal Navy all-steam frigate which had been commissioned in 1973.

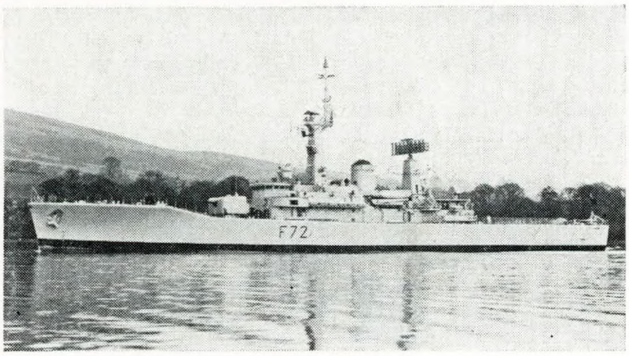

FIG. 12—*H.M.S. Ariadne*

As a consequence it was very difficult to make direct comparisons between the machinery of the last all-steam frigate and the first COGOG destroyer machinery. After all, nearly 20 years separated their design dates. However, there were a number of quite significant points where direct comparisons were valid and worth noting. Mr. Rimmer had selected one, which was: Where does all the heat go? Table I summarized the situation and it should be noted that Type 21 data rather than Type 42 had been

TABLE I

	Leander	Type 21
Design shp kW	30 000	50 000
Full power heat loss to atmosphere as percentage fuel heat	23 per cent	74 per cent
Full power heat loss to sea as percentage fuel heat	60 per cent	1 per cent
Installed exhaust gas duct x-sectional area	basis	four times basis
Installed cooling water x-sectional area	basis	44 per cent of basis

used simply on the grounds of availability of information. In COGOG plant practically all of the heat loss was to atmosphere whereas in the steam plant most of the heat loss was to the sea. This, coupled with the very large demand for combustion air by gas turbines compared with boilers and the need for four gas turbines, four diesel generators and two auxiliary boilers compared with two main boilers, two diesel generators and one auxiliary boiler in the steam plant led to a disproportionately large amount of exhaust gas ducting. The fact that the exhaust gas ducting had to be led high above sea level compared with condensers and cooling water pipes close to the ship's bottom could do nothing to ease the naval architect's stability problems.

Captain Warsop had made the point that in the early days of COGOG development it had been generally thought that elimination of high pressure steam systems, exhaust steam, gland steam, feed and drain systems would drastically cut down on machinery space pipework. It might be of interest to note that the installed length of piping in Type 21 machinery spaces was some 40 per cent greater than in the *Leander* machinery spaces, and the numbers of pipes in the two ships as a whole were practically identical. In addition, the greater use of electrical auxiliaries and the advent of electric/electronic controls in Type 21 meant that the machinery space cable length was about four times greater than in *Leander*.

The authors had drawn attention to the complexity of the C.P.P. hydraulic oil systems, and rightly so. Mr. Rimmer said that as a result of his previous job for Y-ARD Limited he could recall that the first C.P.P. system developed on paper for Type 42 had been based on a fairly conventional screw pump "constant pressure" arrangement. Everything that he had seen and heard subsequently on this subject had reinforced his conviction that Type 42 and Type 21 would have benefited from its retention. In

H.M.S. *Ambuscade,* the first of Yarrow's Type 21s, flushing of the C.P.P. system, in accordance with the specified requirements, had taken 29 weeks, including four weeks in dry dock. As a result of this experience, Yarrow had revised the whole process, but even so, the best they could hope to achieve was to cut the overall time down to about 15 weeks for subsequent vessels.

On the subject of piping systems in general he asked if the authors could indicate if it had been found practicable in *Sheffield* to effect a significant reduction in the number of screwed and flanged joints by the adoption of *in situ* welding and brazing, or by any other techniques.

COMMANDER E. R. MAY, F.I.Mar.E., said he was glad there was no need to comment on the performance of the propellers themselves. However, he would like to comment briefly on the hydraulic system, which had been criticized partly because of the amount of pipework involved. This criticism was quite fair, but it did result, to a considerable extent, from the positioning of the major fittings in the system in places which made quantities of pipework inevitable. Any C.C.P. hydraulic system should be grouped as near its oil transfer box as possible. There were several warships at sea giving an excellent example of this, and he commended it strongly for future warships.

He had detected a note of surprise in the authors' comments that hand control of the propellers was not particularly difficult. In practice, the rate of pitch movement possible in a large C.P.P. was such that a watchkeeper could quite easily control it by hand.

Much had been said about the shore trials of systems. his company had learnt a lot from the shore trials of the C.P.P. system. During those trials they had not been able to load the propeller properly. In any future system they would need to do this, and would want to use the first model of the production controls and production hydraulics in conjunction with the ship's shafting, or such of it as was necessary, and rotate the shafting up to full speed. Had this been done no doubt all the small things which had added up to a considerable nuisance value in the first Type 42 and 21 ships at sea would have been found out and, with any reasonable luck, nearly all of them would have been put right ashore. This was now the practical in commercial C.P.P. development.

CAPTAIN A. A. C. GENTRY, R.N., F.I.MAR.E., said that in the early days of the design development of the Type 42 destroyer he had taken a considerable interest in the advantages to be obtained from the use of the model techniques. The authors had briefly mentioned under the heading, DETAILED INSTALLATION DESIGN: "The model is useful also to the installation trades". This had been an early consideration but it had not been too clear to him at the time exactly how and to what extent the model would prove to be useful in this context. He asked if the authors could expand a little on this.

With regard to the use of the model for traning purposes at H.M.S. *Sultan,* he assumed that it would be a practical visual aid, but he wondered if it was intended additionally to demonstrate "Upkeep-by-Exchange", at least for the major items.

COMMANDER B. J. AUSTIN, R.N., F.I.MAR.E., who had stood by the Engineer Officer of H.M.S. *Sheffield* and had been relieved just before she had gone to sea, said that he had liked the slide Capt. Slijp had shown of *Tromp's* SCC/MCR layout, and also the push-button control system which he believed had already been mooted by A.E.L. for future British ships.

He strongly endorsed the author's comments on the ergonomics of the engine control panel. He hoped there would be a change in this direction in future ships.

He had heard nothing during the evening about H.P. air couplings, and hoped he could assume that these were now all right.

With regard to Commander May's comments, hand control, in his own opinion, was a fine emergency procedure, but if it was to become, as there was a danger it would, a standard exercise at, say, places like Portland, then he felt that far better communications and instrumentation would be required.

Commander Austin then pointed out that there had been a number of highly qualified R.N. engineers and technicians standing by HMS *Sheffield* from before the time of her launch to the time of her acceptance from the shipbuilder. Was it the opinion of the authors that the considerable cumulative skills and experience of these men had been properly exploited during this period?

COMMANDER COOPER, M.D., R.N. said that the authors had prepared an excellent summary of the essential features of the new design—he had played a small part in its original conception. It had been disappointing to read rather reluctant references to the built-in machinery removal trunks expressed with almost an air of apology. "Damned with faint praise" might sum up the attitude. As one of the team that believed that when the organization said that it wanted Upkeep-by-Exchange, and the increased availability this implied, it meant it, it had been with grim determination and against a legion of critics that the removal trunks had been retained in the design. He was convinced that this was a correct decision from which operators in the future would benefit. The fact that the fixed trunks provided in the Type 42 had not been featured, even less insisted upon, in contemporary similar designs meant to be operated on the same policy, was something which he felt the Service might well live to regret.

It was also disappointing that the design still did not feature any "self help" lifting equipment to move machinery in the removal routes outside the machinery spaces. For many exchange procedures adequate dockside craneage would be essential. This was fine in the Royal Dockyard, but not so clever in a minor port on the East African coast.

Upkeep-by-Exchange in itself was a fine sounding phrase which rolled easily off the tongue of one seeking to convince both his seniors and juniors that the old problems everyone had learned to live with for so long had been magically swept away. He was of the impression that, having built in the facilities, there was a feeling that all one had to do now was provide oneself with the appropriate stocks of spare machinery and change this around when it broke. The implications were much wider and infinitely more subtle. Illustrating this point he said that four years ago, when his last ship had seen 10 years of active service, modification No. 1 had been fitted to her main boiler combustion equipment. At the last count the modification total on the Rolls Royce Tyne module, including the G.T.C.U. had been about to exceed 600. The count on the Olympus module was well into the 3000's. There was an obvious and deliberate difference between the philosophy of the aero-type engine designer and the traditional marine engineer. There were many reasons for this which need not concern the present audience. Aero engineers grew up with the problem and developed a slick organization to cope with it. The marine world was only just beginning to appreciate what a problem this might be. The essence of the problem could be summed up by asking whether, in 1986, a new factory fresh warranted change unit delivered from an aeroplane in Hong Kong was going to fit the 1973 vintage module in an aging Type 42 alongside H.M.S. *Tamar*. If it were an Olympus and it was this year, there could be at least two reasons why it might not. If it were a Tyne there could be no less than eight.

This was just an example. The modification rate on other equipments might not be so terrifying, but nevertheless its exchange policy demanded a supporting organization with the capability and resources to iron out the problems which were bound to arise.

He wondered what it would be like serving as an engineer in a Navy with "throw-away" machinery. The operators might well be delighted. The through-costing sums looked encouraging, but could the expense of such a policy continue to be justified? Would one have to sacrifice some more desirable aspect of a warship design because the necessary cash had been spent on spare machinery? What sort of artificer would one have 10 years hence who might believe that when a machine went wrong it was right to fit a new one rather than investigate and rectify the original defect? Would he be able to cope in a situation where replacement was not possible?

There were many questions which sprang to mind under the general heading of "support". He felt that it was essential to maintain continuous attention to the detail of the problems generated by the U-by-E policy if the glitter of the initial success of the design was not to be tarnished.

MR. A. N. S. BURNETT, F.I.MAR.E., asked if pipework in the Royal Navy at present received the attention it deserved. In his own experience it was often a bone of contention later on when the ship was in service if the pipework was longer than it need be, or the runs more difficult than they need be, difficult of access, etc. During the last year while involved with a marketing research assignment and visiting a large number of European shipyards building merchant ships, he had discovered that the merchant marine was in fact giving quite considerable attention to the design of pipework and its installation, maintenance, welding of pipes, welding of valves, etc. Was the Royal Navy investigating such matters? The maintenance of and welding of valves to pipelines might sound minor but in fact could become quite a major matter in the maintenance spectrum.

Correspondence

CAPTAIN H. G. HAFSTRÖM wrote to say that the two series of *Spica* FPBs in the Royal Swedish Navy were all-gas turbine vessels utilizing CPPs. They could also be described as COGAGs in the sense that, according to circumstances, they were run by one, two or three shafts, each connected to a RR Proteus gas turbine. The engines, however, were not mechanically connected; the controllable pitch propellers of the idling shafts were feathered to decrease drag.

He had some questions to ask the authors based on the *Spica* experience. The torque tubes between turbine and gearboxes in H.M.S. *Amazon* developed unacceptable vibrations. Were the high speed tubes in H.M.S. *Sheffield* of metallic diaphragm or rubber type? Workshop balancing of the rubber coupling torque tubes of the *Spicas* to the standards set by the torque tube manufacturer had not been enough to satisfy the low vibration limits on the engine. The solution seemed to be *in situ* balancing. Had the authors come to the same conclusion?

Another subject was the control of the propeller pitch. The authors had reported initial inaccurate and unstable control and described the modifications introduced into the hydraulic system. Had the type of control by swashplate pumps caused these difficulties? One of the concentric oil transfer tubes apparently acted as feedback signal to the running and stand-by pump. The number of pipes, links and the amount of oil seemed to be more complicated than the *Spica* installation with constant displacement pumps and a control valve in the hub. When the authors, under the heading The "CPP System" made the comment that a single control valve would be satisfactory, did they mean an inboard or hub-mounted valve?

The DDR diagram in Fig. 10 lacked the time scale and zero lines but, despite that, was of interest. The shaft speed (4) rose considerably during the pitch reduction period. Which was the overspeed, as a percentage, at crash stop from full speed ahead?

The fuel consumption in Fig. 11 showed improvements when only one shaft was operated. The windmilling propeller would apparently produce a considerable drag at 14 000 kW power on the working propeller. Had a featherable propeller been contemplated to increase the operating range and reduce the risk of cavitation erosion of the windmilling propeller?

MR. M. F. CLOVER wrote saying that where the authors had referred to the constraints on the loading on diesel alternators if acceptable overhaul intervals were to be achieved, they were no doubt alluding to the "coking up" of the diesel engine when running for long periods at low load. This was indeed a weakness but in general the diesel engine was extremely flexible, being capable of rapid starting and remote control. Moreover it was an independent power unit not requiring an assured supply of high energy steam, so that even the "all steam" frigate *Leander* was fitted with diesel engines as well as with the "flexible" steam turbo-alternators. It was agreed that the size and number of diesel alternators did need careful matching to the electrical loads expected. The same comment was true of steam turbo-alternators if sufficient operation was to be attained.

There was some inconsistency in the paper, in that in the comments under "Electrical Power Generation" the need for fitting diesel alternators was apparently questioned, whereas in the section on "The Basic Design" it was stated that the choice of prime movers was straightforward, steam turbo-generators not being considered for obvious reasons and no suitable gas turbo-generators being available. The reason was that the small gas turbine was not competitive with the combination of piston engine and turbo-driven compressor of which the modern turbo-charged diesel engine was comprised. The combination of the gas turbine for the high powers and the diesel engine for the low power requirements was therefore the best combination for the non-steam warship. Diesel engines could also be used for propulsion at cruise speeds, which would halve the fuel consumption between 0 and 6000 kW (shown on Fig. 11), thus effectively doubling the cruising range or halving the fuel capacity required.

CAPTAIN A. A. C. GENTRY, R.N., F.I.MAR.E., added to his comments during the discussion by stating that the authors had mentioned a ± 10 mm accuracy from the model to the ship. The lining up of tanks to the pre-formed pipe systems would seem to be a clever idea to accommodate this. He asked if the authors could give some further information on the installation tolerances and degrees of interchangeability achieved in actual construction.

Authors' Replies

MR. G. STANDEN, O.B.E., said in reply that the thing that decided whether a design was going to meet the programme or not, was not putting in the big pieces of equipment, but making and installing the pipework.

Mr. Rimmer had asked if it had been possible to eliminate screwed joints in Type 42. Assuming the question referred to proprietory couplings the simple answer was "No", and he was disappointed that more had not been achieved. What they had done, as far as T-pieces and reducers were concerned, was to take nuclear submarine experience and use extrusions, swagings and butt joints. These techniques could be done in any copper alloy piping and were the result of an extensive development and proving programme at Barrow. The size limitation was down to about $1\frac{1}{2}$ in (38 mm) o.d. There was no upper size limit. Wall thickness was up to $\frac{1}{2}$ in (12·7 mm). The techniques enabled mechanical joints to be eliminated, weight reduced and provided much neater system arrangements.

A proprietary type of 'O' ring coupling was used for all joints in the HP air, hydraulic and C.P.P. systems and the result was a multiplicity of mechanical joints each containing at least one rubber 'O' ring. The shipbuilder, in view of previous experience, and bearing in mind the express wish of another branch of the Ministry to reduce 'O' ring pipe joints to the minimum to save maintenance effort, was opposed to the use of the particular design of joint chosen. Some problems did occur during installation and commissioning and the results of service experience would be watched with interest.

Many lessons on piping design and manufacture had been learned from building H.M.S. *Sheffield* and these lessons would be used to the full in the design of the Anti-Submarine Cruiser which would have virtually all-welded piping systems. All systems would use either butt welded or sleeve welded joints; the development of the latter requiring an extensive programme of design and testing for thin walled copper nickel pipe. Valves were now available for HP air and hydraulic systems suitable for welding into piping systems, so that the all-welded HP air and hydraulic systems was now possible.

Reference was made to Cryofit couplings, which were made from a titanium alloy which had a memory. A sleeve was made from the alloy having a bore slightly smaller than the pipe o.d. The sleeve was immersed in liquid nitrogen and expanded, using a mandrel to a size slightly greater than the o.d. of the pipe. Provided the sleeve was maintained at liquid nitrogen temperature it retained the size to which it had been expanded, but when allowed to return to room temperature, it tried to return to its original size. The result was a pipe joint which was now approved by the Ministry for HP air and hydraulic systems up to 276 bar and in sizes up to 20 mm o.d. Further development of the design was in hand to increase the maximum diameter of pipe for which the coupling could be used and to make it acceptable for use in sea water systems.

One of the problems that every shipbuilder experienced when going to a welded pipe system was the availability of welders. Everyone suffered from union demarcations, and the thing that killed a lot of welding of pipe systems was who welded them, which depended on the system. In Barrow, for instance, one might have a boilermaker, a coppersmith or a plumber welding a pipe. Pipe materials and pipe sizes for different systems could be identical, but different systems had to be welded by different trades, so one had to have available a plumber, a coppersmith and a boilermaker approved in welding the same material and the same pipe size. One day one might have a surplus in one trade and a shortage in another, and *vice versa.* It should not be forgotten that training a good pipe welder to the standards required by the Ministry would cost something of the order of £400, which was a lot of money to spend if the person involved was duplicated or triplicated and not fully employed.

With regard to Captain Gentry's question about models; the model was now seen as the designer's tool. It was outfitted by the draughtsman and the designer responsible for the systems. One could now afford to alter systems. If a system did not look right it could be taken out and done again, and the man who was doing it had a much greater interest in it.

For the Type 42, models of all machinery spaces and other areas containing large piping runs were used. In addition to using the models to obtain optimum piping arrangements, they were used for maintenance demonstrations and for lifting manufacturing details for the pipework. This latter information was lifted by hand from the model.

Models would be used in the future, but the technique of lifting information would be greatly improved. The ordinates of all pipe bends, etc would be taken by telescope and fed into a computer programmed with full information regarding the system concerned. The computer, through the medium of a drum plotter, would produce an isometric drawing of each pipe; list the length of pipe required, and produce a complete fittings list. In addition to the isometric drawing of the pipe, the computer also produced the complete manufacturing details in digital form, which was now the accepted method used in Barrow for piping manufacture. The overall result of the above would be a saving in draughtsmen's time; reduction in manufacturing time and the production of more accurate pipes.

Commander Austin had raised a point regarding exploitation of the skills of Royal Naval officers standing by. This was a very delicate subject. Unfortunately, one did not live in an ideal world. The unions had to be considered, and unions had their past practice and demarcations, and until one overcame that type of problem it would be very difficult to use Royal Naval personnel to commission the ships. Also, it should be kept in mind that the commissioning teams in the shipyards were now very experienced in this kind of work, and it was open to question whether, during the commissioning phase, these commissioning engineers were not better in actually doing the commissioning trials than the ships' officers.

CAPTAIN J. C. WARSOP, R. N. replied saying with reference to the many questions on pipe systems the Ministry acknowledged the significance of what had been said and were probably putting more resources into the conceptual design of systems, investigating systems materials and methods of construction than they had ever done before.

Referring to the point raised by Captain Slijp, Royal Netherlands Navy, regarding the use of low grade steam for hotel services, the sentiments expressed were agreed and it was most probable that in future destroyer types the Royal Navy would avoid the use of steam for auxiliary services. This view was based upon in-depth studies into life cycle cost of such systems, covering procurement, installation, maintenance, fuel consumption, etc.

The philosophy regarding interchange of components within the control system had been pursued in Type 42 in that standard modules had been developed for the logic control and surveillance functions and these formed the basic building blocks from which the control system was built. As such modules performing similar functions within the control system were interchangeable within the system, and in addition spare modules were carried within the console housing for use in appropriate positions as the occasion demanded. It was the intention that rectification of defects arising in service should be dealt with in this manner and repairs to electronics within the modules should be undertaken by specialists ashore, except in cases of emergency. In this context the intentions of the Royal Navy and the Royal Netherlands Navy were similar.

With regard to Commander Cooper's remarks, Captain Warsop said that whilst he appreciated the general tenor and scope, he was not entirely clear on all the precise points which Commander Cooper wished to pursue. Certainly the U-by-E policy had been pressed with vigour, investigations started with definition of the repair policy for each and every equipment, i.e. throw away, repair *in situ*, U-by-E etc, and were followed through step by step to definition of U-by-E removal routes, exercising removal in the mock-up and ensuring that correct lifting gear was provided. As stated in the paper, all this was fully documented. It would not be pretended that a totally correct solution had been achieved the first time, but evidence to date was that any shortfall would not be great.

In Type 22, the U-by-E concept had been developed further. The total number of removal routes was greater than in the Type 42, these being split into two groups, i.e. Condition 1 Routes which were for use whilst the ship was in service and permitted removal of items which could be removed without withdrawing the ship from service, and Condition 2 Routes, to be used for the larger and more complex items to be removed whilst the ship was in the Dockyard for refit.

With regard to the remarks on "self-help lifting equipment" outside machinery spaces the need for such facilities was recognized and comprehensive instructions and equipment had been provided for the removal of all significant machinery items within the ship. Many of these procedures did not require outside facilities, but it was recognized that without adequate craneage it would not be possible to change certain machinery items and hence the change of major items as envisaged by Commander Cooper would not be contemplated in a minor port on the East African Coast. Speaking specifically of the propulsion gas turbines, the position was that the Olympus and/or Tyne could be changed anywhere in the world subject to the availability of a crane alongside the berth. Mobile Fleet Maintenance Groups had been trained for this task and they had already satisfactorily undertaken changes in the United Kingdom.

The point made by Commander Cooper re introduction of modifications which impact on interchangeability was very relevant, in that control of modifications was an essential ingredient of U-by-E. Suffice it to say, the Ministry realized that the extant procedures for control of modifications would be inadequate for such equipments as aero gas turbines, where the modification rate was inherently very high compared to the more conventional marine equipments. New procedures had, therefore, been developed and implemented.

Perhaps at this stage the general point should be made that support of gas turbine ships had, by the very nature of the systems and equipments themselves, caused the Ministry to revise many of its established ideas and concepts on support whilst in service. To co-ordinate these activities Support Managers were now specifically appointed to each major ship project.

As far as the small items of equipment were concerned, the margin built into the system was such that on loss of, say, a centrifuge or a pump, the full operational capability of the ship was retained, i.e. immediate U-by-E could not be deemed essential, the change taking place at the earliest convenience.

The point raised by Commander May in regard to the positioning of pipework was very much taken as made clear in the paper. Complexity in the after engine room was readily apparent and in major part this stemmed from conceptual decisions taken early in the design. There had also been increasing complexity of the CPP system as it grew during installation.

Hopefully, the lesson had been learnt and in Type 22 when detailed functional changes to systems were being considered installation aspects were very much to the fore in establishing the balance.

With regard to the operation of the CPP system in local manual control, it was initially envisaged that a 17 year old stoker would be required from time to time to control a pump with a variable speed and a variable swashplate. Whilst this operation had been satisfactorily demonstrated a problem arose in the co-ordination of the control and communications, which was not ideal. Fortunately, local control was turning out to be very much an emergency mode; in the year since *Amazon* commissioned local control had not had to be resorted to, apart from deliberate exercises.

With reference to the point raised regarding shore trials of the CPP system, the term "shore trials" could be somewhat misleading. In the case of the Type 42, these tests comprised one shaft line with the shaft stationary in air and using a motor driven pump only. It was true that these trials resolved some problems, but could not hope to cure all problems since it was a trial devoid of the majority of functional ship parameters and the systems which would be in use.

In *Sheffield* and *Amazon* only minor troubles had been experienced with couplings in HP air and hydraulic systems, and the last two ships on sea trials had given no problems at all in this connexion.

He referred Commander Cooper to Commander Austin (Commander of an Artificers' Training Establishment) to discuss the question of what sort of Artificer there would be in the Royal Navy in ten years time.

A wealth of data had been obtained from *Amazon* which had completed both Arctic and Tropical trials with great success, and this data was being fed into the Type 22 design. There was, however, some difficulty in implementing change as there was only a short overlap period between the trials of *Amazon* and *Sheffield* and the building of Type 2201. Fortunately no fundamental changes were required in Type 22, it being essentially a repeat of Type 42 in which nothing disastrous had arisen which led to such changes being required.

Captain Warsop thought it fair to say that the auxiliary power systems had raised a range of detailed and niggling problems, eg the mixture of electrics and steam had given rise to auxiliary boiler control problems when the evaporators were shut down and there was a terrible low load in only heating water for the Ships Company. As stated earlier for ships of 4000 tonnes and below "all electric" auxiliary systems would solve this problem. He felt the majority of the problems had probably stemmed from over-concentrating attention on the Main Propulsion Plant itself and also from somewhat insufficient attention on auxiliary systems; this was readily understandable in light of the magnitude of the change to the propulsion plant.

Captain Warsop pointed out that in gas turbine ships a high proportion of the maintenance work was akin to that as in steam ships. What had gone was all the high pressure steam pipes, majority of steam drain systems, steam driven auxiliaries and the boiler maintenance, much of which involved tedious repetitive work.

The Engine Room complement of 29 in *Amazon* had, to date, contained the maintenance load, with planned routine assistance from Fleet Maintenance groups.

The point made by Mr Rimmer regarding the reduction of waste heat was agreed and posed new problems in ship design, affecting not only the Naval Architect. The percentage increase in the length of pipework quoted was somewhat surprising, but did not pose such a problem as would appear on face value since the greater proportion of the pipework in a gas turbine ship was of a smaller diameter, with reduced need for lagging, and there was increased flexibility in layout.

Mr Standen had already remarked on the extent of utilization of the RN Ships Company for the operation of machinery during trials. Captain Warsop would add no more to these remarks other than that the problem, as he saw it, was to achieve a judicial balance between the acknowledged experience and expertise of shipbuilders' test groups in commissioning individual systems, the Unions and the wealth of general experience of RN personnel in control and surveillance of machinery installations as a whole, the experience of the marine engineering officer as a member of the joint test group, specialist system and equipment training given to RN personnel, and the need for Ships' Companies to acquire a feel for the particular machinery installation before the ship was accepted, so that on the day of handover they could safely drive her away.

MR. J. BOWES replied saying:

Salt Filtration Measurement

Various instruments were available for measuring the salt content of the combustion air but these were all bulky and elaborate and only suitable for use under laboratory or closely controlled shipboard conditions. At present there was no known equipment available for general shipboard use although such an instrument would be desirable. The salt filtration equipment which was used had been developed as a result of extensive testing and it was not expected that this would be a problem area.

Read Across to Type 22

As would be expected the development of the Type 22 design had gone ahead with frequent scrutiny of corresponding areas in Type 42. Type 22 was only different from Type 42 in these areas where it has been of advantage to change and in general the changes were of a detailed nature, mostly aimed at ironing out the few tight areas in the machinery spaces. One particular point of difference in the two designs was that Type 42 had a machinery removal trunk from each auxiliary machinery room whereas Type 22 had portable plates which were removed to open up the removal routes from these machinery rooms. The Type 42 arrangement might be regarded as the ideal from the aspect of the machinery but it did lead to loss of ship space in a very valuable part of ship; for this reason it had not been followed in Type 22.

Piping and Models

The numerous questions raised on the subject of piping emphasized once again the importance of this to the overall machinery installation. Piping was possibly the most expensive single item in a ship and it could make or mar the basic machinery arrangement, particularly in an installation in which great emphasis was placed on maintenance and Upkeep-by-Exchange. It was generally acknowledged that the way ahead lay in the field of models and this was reflected in the ever increasing effort which was going into modelling at the various stages of the development of a machinery design.

Mr. Rimmer's remarks on the increased pipe lengths in Type 21 as compared with Leander were most interesting. It was felt however that it was not only the pipe length that mattered but also the pipe bore, what was in the pipe and the pipe runs; perhaps a truer comparison would have been on the basis of pipe volume, including lagging. The point was taken however that one still had a lot of piping in gas turbine ships even although most of it was at relatively low pressure and temperature and did not result in uncomfortable habitability conditions in the machinery spaces.

★ ★ ★

The authors replied jointly to correspondence received stating that the brief description of the *Spica* FPBs was of interest particularly with respect to the use of feathered C.P.P. to decrease drag from shafts not driving and although no details were given it was assumed that the control system contained interlocks to prevent overstressing of shafting by the application of power to a shaft with the propeller in the feathered position and that some form of shaft break was used.

The design of actuator used within the hub of the C.P.P. used in the Type 42 and 21 design had a limited total angular traverse and since the manoeuvring performance of the ship dictated the use of a zero thrust position for ship stopped and the application of fine pitch for slow ship speeds utilizing the power turbine energy at minimum self-sustaining speed, it followed that a feathered position could not be utilized without sacrificing these two quantities. It was true that with the blades in the feathered position the drag would be decreased, hence enhancing fuel consumption on single shaft operation. but the design of a propeller design which went through the feathered position, in lieu of the present zero pitch design, would dictate the use of angular movements of the blade outside the scope of known propeller design in the power range in use. Complex logic would also be required to ensure that the feathered position would not overstress the shafting.

The decrease in specific fuel consumption indicated in Fig. 11 was that arising from the use of single shaft operation only with the non-driving shaft trailing, the pitch being selected at the design value. Single shaft operation with the non-driving shaft at zero pitch was possible and might be employed where there was a need to prevent the non driving shaft from turning. The increased drag under the latter mode of operation would further restrict power on the driving shaft to prevent excess stress levels and would certainly lead to excessive cavitation.

The basic flexible driving member between gas turbines and gearing was identical for both the Type 42 and Type 21 designs except for the length as described in the paper and consisted of a hiduminium torque tube having a flexible metallic coupling at each end. The early vibration problems described in HMS *Amazon* occurred following installation of the coupling assembly in the factory balanced condition and the vibration persisted albeit at a much reduced level following attention to detail whilst fitting replacements and *in situ* balancing. As stated in the paper, the solution in the case of Type 21 Class was the introduction of a revised design of increased diameter which was now satisfactory. *In situ* balancing of the new design was still found to be necessary for satisfactory service but in contrast the original but shorter design for the Type 42 had performed adequately without the need for such balancing.

With reference to the control of the C.P.P. the problem was not one generated by the use of swash plate pumps but of dead band within the hydraulic system and was overcome by a modification to the shuttle valve within the composite valve unit. It was now believed that this modification would not have been necessary had the subsequent modification to increase the swash plate servo pressure described been applied at the outset but there was no practical evidence to support this theory and there was no intention to remove the initial modification to the shuttle valve. The purpose of the concentric oil transfer tubes was to convey pressure oil to and displaced oil from the hub/piston assembly and not as described by Captain Hafström, and the feedback to the controls was via the outer tube. The use of terms "running and standby pumps" was not correct and the system employed a shaft driven and a motor driven pump on each shaft, the former being the normal running pressure source and the latter being used for initial starting and stopping and for use when an increased pitch change rate was required.

As stated in the paper, in the light of experience it was apparent that the system was in fact grossly oversized and that the required function could be achieved by a simple open loop system, and the reference to a simple control valve in this context would be an inboard mounted unit. There were no intentions to change at this point however despite the complexity of the system as at present and the high initial modification rate, since experience had shown that the system was now capable of achieving the designed response and accuracy.

With reference to the point raised regarding the DDR trace in Fig. 10 of the paper, the shape of the traces varied dependent upon the initial and final conditions of the manoeuvre and the propeller rev/min curve in the paper was one from a trial in which there was a more drastic rise than that arising as routine. During a crash stop from full speed ahead the maximum speed experienced was only 102 per cent of the maximum shaft rev/min and did not at any time approach either the partial overspeed switch setting of the gas turbines set at 108 per cent or the mechanical overspeed setting of 110 per cent max rev/min.

The remarks by Mr. Clover in the first part of his contribution were agreed and considerable care was taken to match the loading with the capacity of generators at the design stage, due allowance being made for the expected growth margin required to cater for future increases. The need for fitting diesel generators was not questioned but the constraints on loading to achieve acceptable overhaul intervals posed problems which would not be present in the case of either steam or gas turbine generators—fuel consumption apart. Whilst it was agreed that the small gas turbine was not competitive on this score, from size and weight considerations their use did merit consideration at the design stages if a suitably sized unit was readily available and was also consistent with the U-by-E policy referred to earlier.

In considering the propulsion and generating package for a non-steam warship design the use of diesels was considered very carefully to meet the targets set and it was agreed that, viewed from the specific fuel consumption standpoint, the diesel engine had much to offer. It should be stated however that fuel consumption and hence range was not the sole consideration in determining the power plant and the selection of prime mover was dependent upon that most suited to the overall ship requirements and support policy.