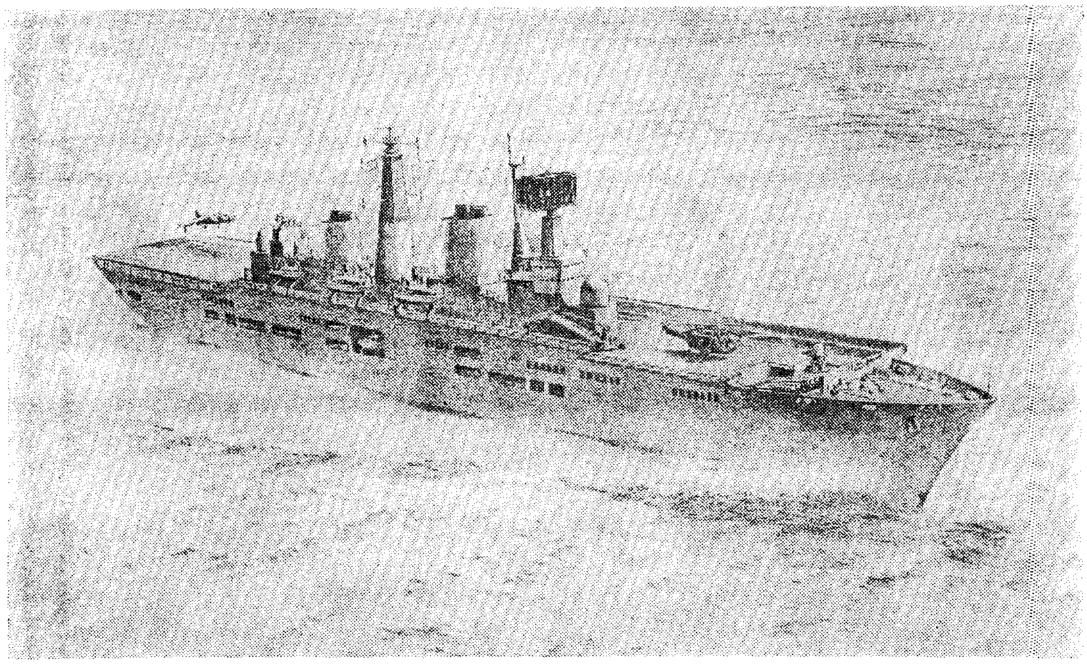

ARTIST'S IMPRESSION OF THE CAH

THE CAH PROPULSION SYSTEM

BY

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The CAH will be a ship of about 19 000 tons and will be comparable in size to the light fleet-carriers. She will combine the functions of command of a fleet with the capability of carrying VSTOL aircraft and helicopters giving her a powerful anti-submarine role. Above is an artist's impression of the completed ship.

Introduction

By the end of 1969, it had been decided that the ship would have two shafts driving fixed-pitch propellers. Each shaft would be driven by a pair of Olympus TM3B gas turbines through a reversing gearbox. This decision precluded the use of the Type 42 gearbox and control system. The MOD, therefore, became involved in the design of a new gearbox and a control system to suit the complex reversing mechanism which the gearbox required.

During the first half of 1970, Y-ARD Ltd. conducted a feasibility study on the propulsion system and the associated auxiliaries, and started to build a $\frac{1}{20}$ scale model of the main machinery compartments and uptake spaces. From mid 1970 until early 1972, Y-ARD Ltd. in conjunction with the MOD have written the main machinery volume of the building specification, and have carried out various other studies associated with the design. Vickers Shipbuilders Ltd., under a general design assistance contract, have prepared diagrams of the systems, outside the main machinery compartments. Y-ARD Ltd. have also built a model of the hull in the area of the main machinery compartments in $\frac{1}{10}$ scale, which has been transferred to Vickers Ltd. for completion. This model will be used as the vehicle for preparing the best layout of the main machinery spaces and will be approved in whole and in detail by the MOD.

Since the end of 1969, the MOD have been developing with various contractors a 1·5 MW Diesel generator, an auxiliary boiler, an air-conditioning plant, a distilling plant, a gearbox, and a control system particularly for use with the CAH.

It was decided in November 1969 that one shaft set of main machinery from the gas turbines to the thrust-block, complete with air intakes, exhausts, lubricating oil system, and controls as for the ship, should be set up ashore for trials purposes. It is expected that initial trials on this will be started at Rolls-Royce (Ansty) in June 1973. Several other pumps have been ordered by the MOD for trials to be conducted at the AMEE. The tender action for the ship has been started and a contract to build should be placed with a shipbuilder in 1973.

Design Philosophy

Having arrived at the basic decisions already mentioned, it was necessary to design all the supporting systems to meet the requirements of a modern warship. A common policy had to be evolved to ensure that there was no wide divergence in the characteristics of the systems both inside the ship and with other ships currently being built and designed.

Throughout the design, the following characteristics were considered one against another to obtain an acceptable compromise:

Performance	Speed Endurance Manoevrability Services: electrical power, air, etc. Minimum manpower
Protection	Noise signature Shock Transit fall-out Machinery to run submerged Watertight sub-division IR signature Ability to withstand action damage
Reliability	Reliability Maintainability Availability
Weight and space	
Environment	Roll and pitch Range of temperature of air and sea-water...... Salt-laden atmosphere
Habitability	
Cost	

At the present time, the designer is being exhorted to reduce the number of men required to operate and maintain the machinery, and also to improve reliability. These two requirements are frequently incompatible. It was decided, however, that the selection of gas turbine machinery met both these requirements.

Performance and, for the most part, protection are specified in the naval staff requirements. Habitability standards are laid down and apply to all ships; environment likewise offers no compromise. Cost too is primarily controlled by the naval staff requirement. However, cost can be saved by designing a simple system with good reliability and low manpower requirement for maintenance, but the system will be more vulnerable—the steering systems in the large aircraft carriers were a good example of where vulnerability was regarded as more important than cost, reliability or manpower. In the CAH, the systems are probably more vulnerable than we have been used to in the old cruisers, but it is hoped that the reliability will be better. Noise signature is another characteristic which is in direct conflict with cost and reliability. Large sums of money will be spent on design and manufacture to meet the noise requirement. If reliability is not to suffer, large sums must also be spent on maintenance and support—for instance, there are 88 rubber pipes in the L.P. sea-water system. Every effort has been made to keep the systems as simple as possible in the belief that simplicity leads to reliability. Weight and space are governed very largely by the policy to use SYMES range equipment wherever possible.

Eventually the compromise between characteristics is narrowed down to performance versus reliability. The designer is bound to attempt to meet performance and modifies his design to meet the reliability requirements. Where there is conflict between the two, it is difficult to express reliability in a quantitative way whereas performance is clearly defined. In these circumstanecs the designer must be careful that he does not accept too much reduction in reliability for the sake of performance.

When reading the remainder of this article one must bear in mind these difficulties which confront the system designer in his effort to achieve high reliability.

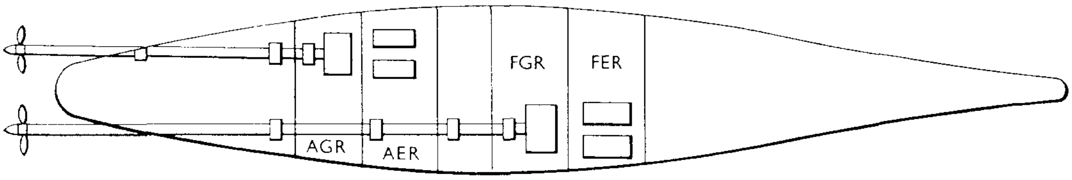

FIG. 1—THE PROPULSION SYSTEM

Propulsion Machinery Layout

The main engines are arranged as in FIG. 1. The four main machinery compartments are open right across the ship with transverse bulkheads between each. The area between the forward gearing room and the after engine room contains naval store rooms and the main workshops. The two engine rooms are separated in this way for damage control reasons and to avoid the impossible congestion of ducting over the gas turbines which would result if they were arranged alongside one another.

The power turbines are connected to the gearbox by torque-tubes and flexible diaphragm-type couplings. The main thrust-blocks are abaft and separate from the gearbox. The port shaft has one plummer-block and the starboard shaft three plummer-blocks. There are two A-brackets on each shaft.

When at cruising power at sea, one gas turbine on each shaft will be running and the other kept in readiness should high powers be needed.

Gas Turbines

Two standard TM3B modules will be used for each shaft. The details of these engines are now becoming well known. On each module, separate noise-enclosures are fitted round the gas generator and power turbine.

Each pair of gas turbines is solidly bolted to a raft which in turn is mounted on soft rubber U-mounts to attenuate noise. There is a system of hard rubber mounts which are set clear of the raft but which can be rapidly shimmed up to support the raft should the soft rubber system prove unstable. If both these systems prove unsuccessful, it is planned to fit a Constant Position Mounting System. A determined effort is being made to avoid using this system in the first place as it is expensive both in first cost and in running cost; it has a mass of moving parts, seals, and diaphragms, which could be a source of unreliability.

The control panels on each module are being so positioned that one man can stand between the modules and control the associated main engine.

The gas generator has a self-contained lubricating oil system, whereas the power turbine is supplied with oil from the main lubricating oil system which also supplies the gearbox and thrust-block.

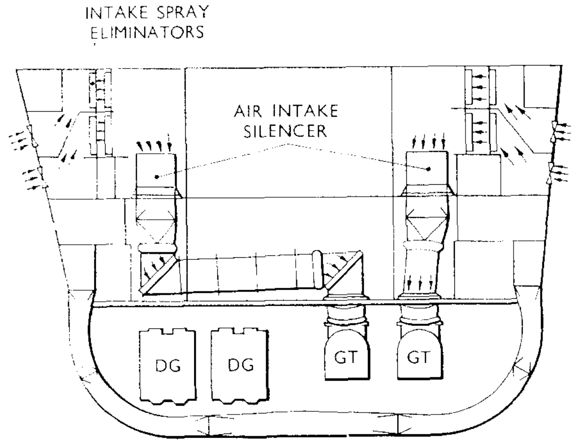

FIG. 2—ARRANGEMENT OF AIR INTAKES

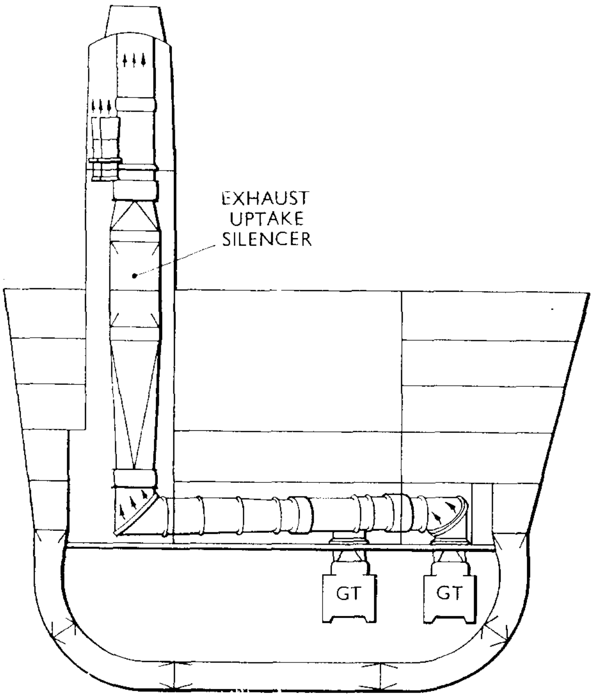

FIG. 3—ARRANGEMENT OF EXHAUST UPTAKES

Ducting

The arrangement of main downtake and exhaust ducting presented a difficult problem which was aggravated by the requirement for all the exhausts to run to the starboard side.

Intake air is taken from each side of the ship as shown in FIG. 2. The air is led initially through a salt/spray eliminator situated at No. 1 and No. 2 deck level. The first stage consists of a chevron type spray eliminator. The second stage is a fibrous pad-type salt eliminator, followed by a repeat of the first stage to collect breakaway droplets from the second stage. The air speed through this system is 25 feet per second which involves a very large opening in the ship's side.

The air now passes through a square-sectioned silencer fitted with flat-plate splitters. From then on, the air is contained within a circular duct of about 7 feet in diameter. This is done both to reduce the noise level in the surrounding compartments and to guide the air into the compressor. The right-angled bends are cascaded to smooth the flow.

The arrangement of the exhaust ducting for the after engine room is shown in FIG. 3. This ducting is also about 7 feet in diameter and made of stainless steel in the hope that it will last the life of the ship. These right-angled bends too are cascaded. The exhaust silencer is 9 feet square in section and fitted with flat splitters. These splitters are made up in sections and bolted into the casing so that in the event of failure, the splitters can be removed without disturbing the ducting. To remove and replace a complete silencer, even at island level, would be a lengthy process involving a great deal of dockyard effort. The ducting supports have to take the thermal expansion and prevent noise being transmitted to the ship's structure. Bellows are fitted in both the horizontal and vertical legs. These bellows and cascade bends, like the silencer splitters, are considered to be vulnerable parts of the system and removal procedures and routes have been worked out in some detail.

A large number of model tests have been carried out on both the intake and exhaust systems; the intakes proved satisfactory from the start, but the exhaust system is bedevilled by the very uneven flow-distribution which emerges from the power turbine exhaust volute. This uneven flow is perpetuated right through each duct. After each test, modifications had to be made to the duct. The criteria throughout has been to remove any area of zero flow as this could lead to flow switching in the full scale, and to limit the maximum gas speed through the silencer to 200 feet per second as this is a critical speed for known splitter materials. It will be noted from FIGS. 2 and 3 that a great deal of space has been taken up by these ducts which have, to a certain extent, dictated the width of the hangar.

Gearbox

A diagrammatic arrangement of the gearbox is shown in FIG. 4. Only the train of wheels from one gas turbine to the main wheel is shown. The drive from the other gas turbine to the main wheel is similar. Both power turbines on each shaft turn inwards so that, with the triple reduction arrangement, the propellers turn outwards.

Considering FIG. 4, manoeuvring is done by sequentially filling and emptying the relevant fluid couplings. These copulings are large and double circuit, and take some 20 seconds to fill or empty. The emptying is affected by scoops as in the DLGs. Coupling drive cannot be used for sustained high power due to the heat generated. For this purpose the SSS clutch is engaged and the couplings are emptied. When changing from clutch drive to coupling drive, the high-speed line has to be decelerated and this is achieved by a brief application of the brake shown in the figure. A main shaft brake is fitted abaft the thrust-block and this is used to hold the shaft stopped when both couplings are empty.

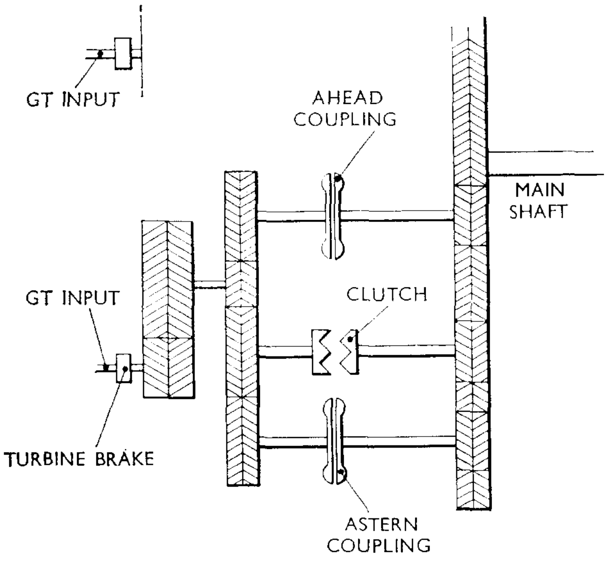

FIG. 4—DIAGRAMMATIC ARRANGEMENT OF MAIN PROPULSION GEARING

The system for filling the couplings is arranged so that either or both gas turbines can be driving at one time, and one gas turbine can be connected or disconnected while the other is on load without changing the main shaft power.

The main lubricating oil

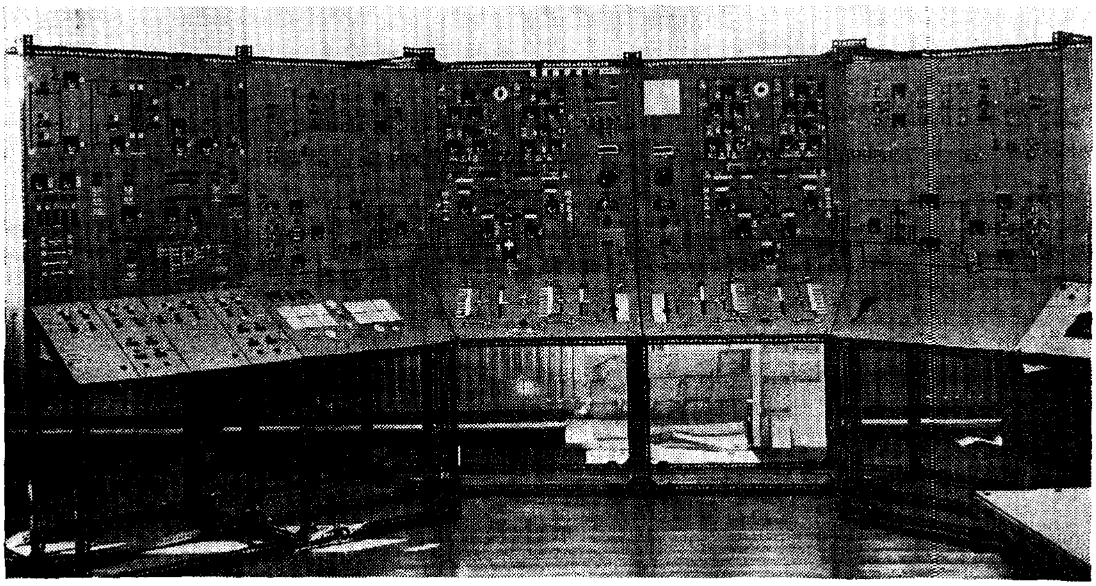

FIG. 5—MOCK-UP OF THE MACHINERY CONTROL CONSOLE IN THE SCC

drain-tank is supported from the under side of the gearcase and projects forward of the gearcase. Three motor-driven L.O. pumps are mounted on this projection. The coupling filling diverter valves, which are hydraulically actuated, are situated at the after end of the gearcase close to the fluid couplings.

Fluid couplings and gear sprays tend to aerate the oil. The affect of this is being limited as far as possible by keeping the residence time in the drain tank up to 1.5 minutes and by fitting a gauze baffle across the tank in such a way that all the oil from the couplings, bearings, and gears has to pass through it on the way to the pumps. This gearbox design was selected from three competitive proposals, and it is worthy of note that the first consideration in its selection was that it was the one most likely to prove reliable in service. The total weight of each gearbox complete with lubricating oil will be 168 tons. This mass will be solidly bolted to its seating, as it is not thought to constitute a noise hazard.

Gearbox Controls

The coupling filling diverter valves, scoops, and clutch operating cyinders are hydraulically actuated, using the same oil as in the drain tank (OEP69). The hydraulic power supply and control valves for this system are situated in a console mounted between the two gas turbines in the engine room. Each engine can therefore be completely controlled from this position which is called the Local Control Position. Certain other controls and instrumentation are brought to this position.

Machinery Controls

So far only the Local Control Positions have been mentioned. From these two positions, situated in the engine rooms, the main engines can be controlled. It is required, however, that the ship should be controlled directly from the bridge, and be able to pass through fall-out with a minimum number of men. To achieve this, there is a remote control console in the Ship Control Centre (SCC), which also contains the primary electrical control console and the NBCD headquarters. This control console is so designed that the machinery compartments are unmanned and are only visited in times of crisis, for visual checking of machinery and routine operations on auxiliary machinery. The bridge has a simple console for steering and propulsion with the minimun amount of instrumentation and with single lever control for each engine. This bridge control is via the SCC control to the local control console and is effected entirely by electric and electronic means. Gas turbines are normally started, run up, and connected or disconnected from the SCC. During this period of change, the SCC will assume control of the engines. On completion of the gas turbine change-over, control is passed to the bridge. Gas turbines cannot be stopped and started from the bridge. The engagement and disengagement of the clutch is automatic and occurs at a defined power.

Throughout the system design, every effort has been made to avoid the use of remote actuation of valves. The one exception to this is the lubricating oil temperature control which is effected by the same control system as the gearbox. There are, however, a few valves in certain systems which are automatically actuated usually by pneumatic power. These valves are part of the SYMES range equipment.

All the pumps in all the systems are electrically driven, and in many cases the motors are started from the SCC but, of course, the valves have to be set manually in advance.

Electrical instruments are used throughout the SCC control console and, although there are a fair number of analogue gauges, most of the instrumentation is done by annunciators. These indicate when a parameter has gone beyond its accepted limits and the machine has shut down (alarm), or when a parameter is reaching an unacceptable level (warning). All the warnings are fed through data-loggers (480 channels) from which a digital read-out can be obtained at any time. This means that the watchkeepers have a minimum number of gauges to watch for safe operation of machinery, but there is a mass of information readily available via the data-logger.

The control console is so arranged that it can be managed by two watchkeepers: one, a POMEM, sitting at the engine controls; the other, a CMEA, sitting back surveying the whole console with communications and data-logger to hand.

Main Forced Lubrication System

Oil is required for the lubrication of the power turbine bearings, gearbox bearings and gears, and for filling and cooling the fluid couplings. When in coupling drive, the total quantity of oil required is about 1600 gallons per minute, and when in direct drive only half this quantity is required. At first sight it seemed preferable to have separate systems for lubrication and for coupling filling and cooling. After study, however, this was discarded on the grounds of both complexity and the large number of pumps required. It was finally decided to have three motor-driven centrifugal pumps with the sort of characteristics which would maintain a reasonably steady pressure throughout the range of duty. Two pumps are to be run with one pump stand-by when the engines are in use. Each pump has two entirely separate electrical supplies with automatic change-over arrangements. The third pump cuts in automatically when required. Shaft-driven and hydrostatically-driven pumps were discarded on the basis of the poor characteristic in one case and complexity in the other. The three main pumps are mounted on rubber on the forward end of the drain tank with a flexible discharge pipe to absorb the movement. An air-driven pump is fitted alongside the thrust-block on its own small drain tank. This pump cuts in automatically in the case of total power failure. It supplies sufficient oil to serve the bearings and gears as the engines come to rest. It follows, therefore, that if there is a total power failure, the ship must be allowed to drift to a standstill as there is insufficient oil available to fill the couplings. The probability of this happening is thought to be remote as eight Diesel generators are fitted, at least

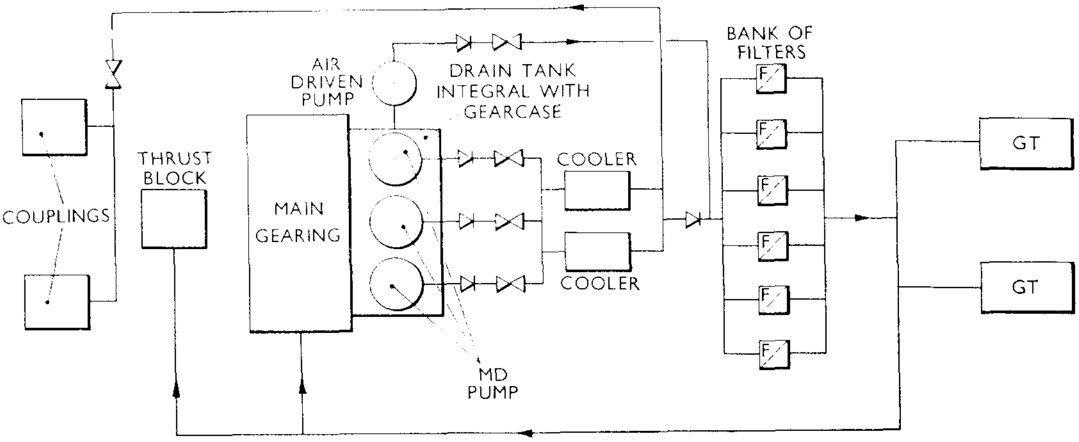

FIG. 6—DIAGRAMMATIC ARRANGEMENT OF THE FORCED LUBRICATION SYSTEM

four of which will be running at sea. Generators can be started from the primary electrical control console in the SCC.

The lubrication system is shown diagrammatically in FIG. 6. Both coolers are normally in use, but one cooler is sufficient to cool the oil with the engines at full power in direct drive in tropical waters.

Since the gas turbines are flexibly mounted, flexible elbows are fitted in their lubricating oil supply pipes; these rubber elbows and rubber bellows at the pump discharges are fitted to attenuate noise. A failure of one of these rubber pieces could bring the ship to a standstill within a few minutes with the possibility of disastrous results to the engine. This is a typical example of the conflict between performance and high reliability referred to earlier.

Dieso Fuel Systems

The main engines, Diesel generators, auxiliary boilers, motor-boat engines, and motor transport on the flight deck, all use Dieso.

The fuel is received through a filling line and distributed via two filling trunks to 30 wing and double-bottom tanks. There is a 200-mesh filter in the filling line but, as all but four of these storage tanks are uncoated, it must be assumed that the fuel is contaminated with corrosion products. It would be extremely expensive to coat all tanks and the coats are difficult to maintain.

The fuel is thence transferred by pump through a 300-mesh duplex filter to the wing tanks situated on each side of each engine room. These tanks are coated and are used as settling tanks, being fitted with drainage and test cocks. From these tanks the fuel is centrifuged into similarly coated service tanks which are situated just forward of each machinery space. This treatment should render the fuel acceptable to the gas turbines. The system is so arranged that fuel can be transferred direct to the service tanks in the event of a centrifuge failure.

FIG. 7 illustrates the fuel supply system for one unit only. The intention is that two pumps will be run, one supplying each gas turbine, with the third pump as stand-by. From the service tanks, the fuel is pumped through a 200-mesh filter, a 5-micron filter, a filter/water-separator, and a reducing valve and thence to the gas turbines. A fine water-detector is fitted in the line.

A small emergency tank is fitted high in the engine room, and the system is so arranged that a failure of fuel pressure causes a non-return valve to open allowing fuel to flow from this tank by gravity to the engines. Filtered fuel is also piped to the Diesel generator and auxiliary boiler ready-use tanks. The emergency header tank and ready-use tanks are kept full through a float-controlled valve. All the remainder of the valves on the system are operated by hand.

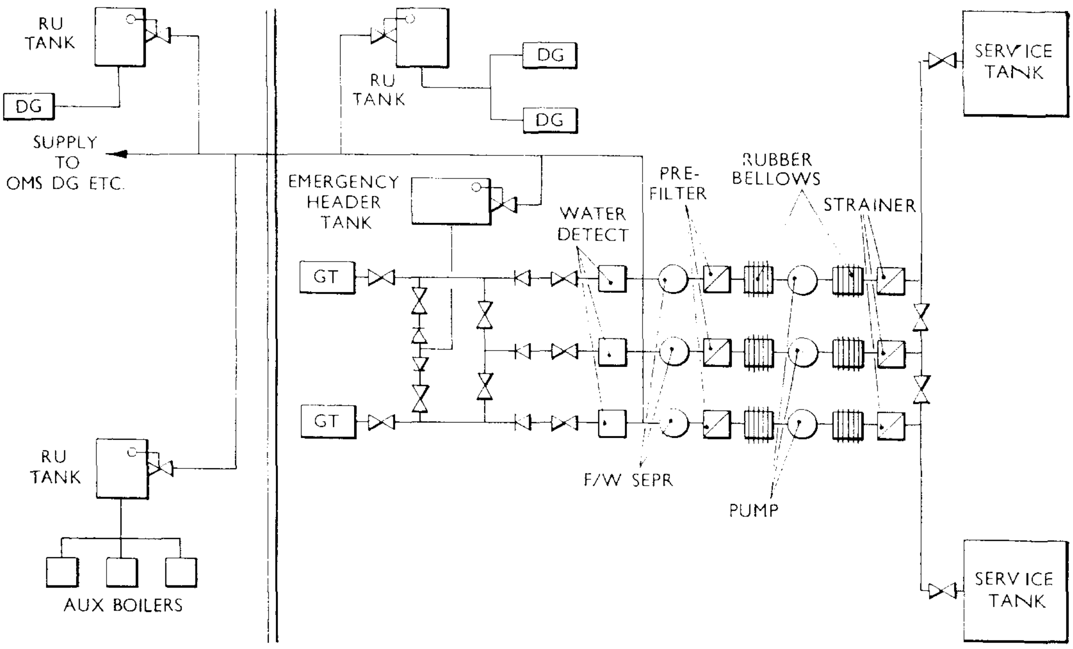

FIG. 7—DIAGRAMMATIC ARRANGEMENT OF THE FUEL SUPPLY SYSTEM IN THE FER AND FGR

Rubber bellows are fitted each side of the pumps as these are mounted on rubber mounts. These pipes are particularly vulnerable in the event of a machinery space fire, because the failure of one would allow both service tanks to drain to the bilge feeding the fire with 100 tons of fuel. To alleviate this danger, the suction valves on the service tanks can be operated via rod-gearing from the deck above. The ready-use and emergency header tanks have dump valves which can be operated by rod-gearing from outside the compartment; the fuel from these tanks is run down into a storage tank.

Every effort has been made to reduce the manpower requirement. During the filling operation, two senior ratings and one junior rating only should be required at the filling trunks. There is a communication link between these trunks, the SCC, and the supplyihg ship. In the transfer system, the duplex filters are cleaned by back-flushing. The transfer pumps are started locally but can be stopped from the SCC when the wing tanks are full. The centrifuges are self cleaning. The 200-mesh filters fitted round the system will have to be cleaned manually from time to time. The fine filters in the supply system should not need a great deal of cleaning as the fuel in the service tanks is already filtered to a high standard.

Sea-water System

The total sea-water requirement for the ship was studied in order to arrive at the best possible arrangement of systems. A large quantity of water is required for cooling the machinery in the main machinery compartments, although this is at a comparatively low pressure (20 p.s.i.). A very large quantity of water at a high pressure (125 p.s.i.) is required for fighting a major fire, and a lesser quantity of water is required for heads and the outside Diesel generators which are situated at No. 2 deck level; as these services are well above sea level, a pressure of 50 p.s.i. is required. There was a determination not to fit reducing valves in the sea-water system because of their unreliability.

The fire pumps with their high duty take a heavy electrical load. There has been concern throughout the design exercise to keep electrical load down. It was

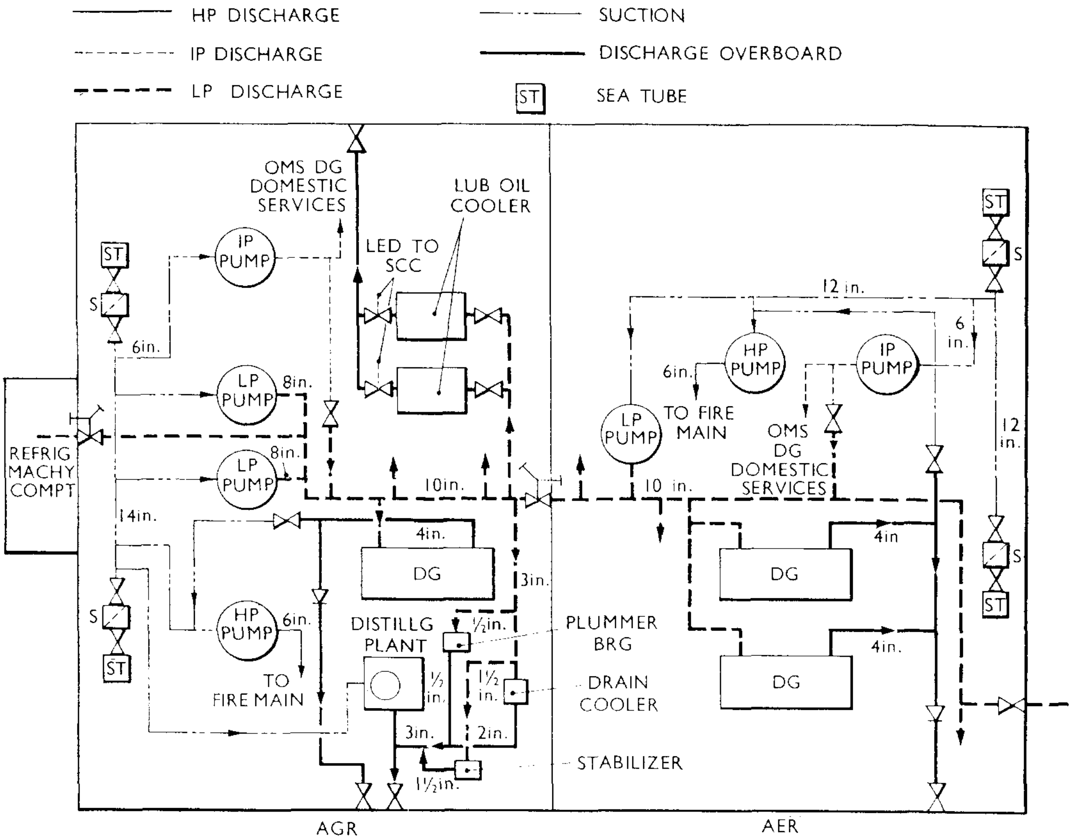

FIG. 8—DIAGRAMMATIC ARRANGEMENT OF THE SEA-WATER SYSTEM

therefore decided to have no continuous users on the firemain so that only one or two pumps need normally be run to pressurize the system. To avoid cavitation erosion in the running pump, the coolers in the various hydraulic systems obtain their supply of water from this system and are designed for full firemain pressure. The firemain is supplied by nine pumps and is built in two rings one above the other with a riser from each pump to each ring. Pre-wetting connections are taken from this system. When pre-wetting is being carried out, the pumps discharge through machinery space coolers, thus the same water which is used for cooling these spaces under closed down conditions is used for pre-wetting.

The machinery cooling-water could be supplied at 50 p.s.i. to cover all the remaining requirements from the main lubrication oil coolers to the bridge heads with one system. However, as most of the water is required at a low pressure, it is plainly very wasteful of power to pump at 50 p.s.i. and then use at 20 p.s.i. The decision is to fit a low pressure machinery cooling system which is contained within the four main machinery compartments, the refrigerating machinery compartment, and the plummer-block and stern-gland spaces.There are six centrifugal pumps for this duty, four of which will be required at full power in tropical waters. Supply is by a single pipe running down the middle of the ship.

A third system has been designed to meet the remainder of the requirements. This consists of three pumps with a discharge pressure of 50 p.s.i. feeding a ring at No. 3 and No. 4 deck level.

The high-pressure system can be cross-connected with the intermediate-pressure system, which in turn can be cross-connected with the low-pressure system. The arrangement of the pump suctions and the low-pressure discharge system for the after unit is shown in FIG. 8.

High-pressure and Low-pressure Air Systems

In order to avoid wear and tear of the H.P. air compressors, the basic requirement in the design of these systems was that there should be no 'continuous user' on the H.P. system. The system consists of a ring in the main machinery spaces, and is used for such services as charging gas-turbine and Diesel-generator starting cylinders, diving cylinders, aircraft servicing cylinders, and a bank of cylinders arranged specifically for driving the air-driven lubricating oil pump. There are two motor-driven H.P. air compressors connected to the system, and two small Diesel-driven compressors for charging two of the Diesel generator starting cylinders.

The L.P. air system supplies many services, such as air-driven tools in the workshops, carboblast for gas-turbine cleaning, actuation of a few valves, and the sewage plants. Two services, fluidic surveillance of Diesel generators and wave-guide drying, are, however, continuous users of air, for which purposes further drying of the air is necessary. The wave-guide drying requirement, in particular, makes the system more critical than in older ships as certain vital radar equipment shuts down automatically on failure of air supply. Three compressors ar fitted. Under normal running conditions, one will be running with a second one standing-by; this stand-by machine can be started immediately from the SCC.

Auxiliary Energy

In a gas-turbine-driven ship, it is by no means obvious how all the domestics should be powered. There is a large number of users of electric power in the ship, and these include the weapons sensors, motors for pumps and fans, and lighting. At first sight, therefore, it would seem desirable to use electric power for all the remainder of the services. This would have the advantage that the low-pressure steam and drain systems, which are such an ugly maintenance load in steam ships, could be eliminated. A study of the best way of supplying the domestic services was carried out.

Initially a generator had to be selected. The largest prime-movers available in the time-scale of the CAH were 1.5 to 1.75 MW and the choice eventually lay between the Paxman Valenta and an American gas turbine. It is interesting to note that when all criteria for selection had been examined the relative merits between these two were evenly balanced. The Paxman Valenta was selected on the basis that its state of development was well in advance of the gas turbine. From the ship design point of view, it would have been extremely difficult to have got the gas-turbine ducting into the space available.

It is expected that the Valenta engine, at present rated at 1.5 MW, will be uprated to 1.75 MW. so a 1.75 MW electric generator has been fitted to it from the outset. Eight Diesel generators is the maximum number which can conveniently be fitted.

The only evaporators at present available are steam driven, but these could be operated by the warm water from the Diesel cooling system; this would, however, require a development programme. Because of the considerable complication of such a scheme, it is unattractive. Two 7-tons per hour flash evaporators are, therefore, fitted, one of which will be sufficient for the whole duty. They will be steam heated.

From the available selection of ventilation heaters, it was apparent that the electrically-heated elements were much larger than the equivalent steam-heated elements and would be difficult to accomodate in the trunking. Steam-heated elements were chosen.

Having accepted that a steam system was a requirement, it was decided that the domestic calorifiers should also be steam heated as this was the simplest and

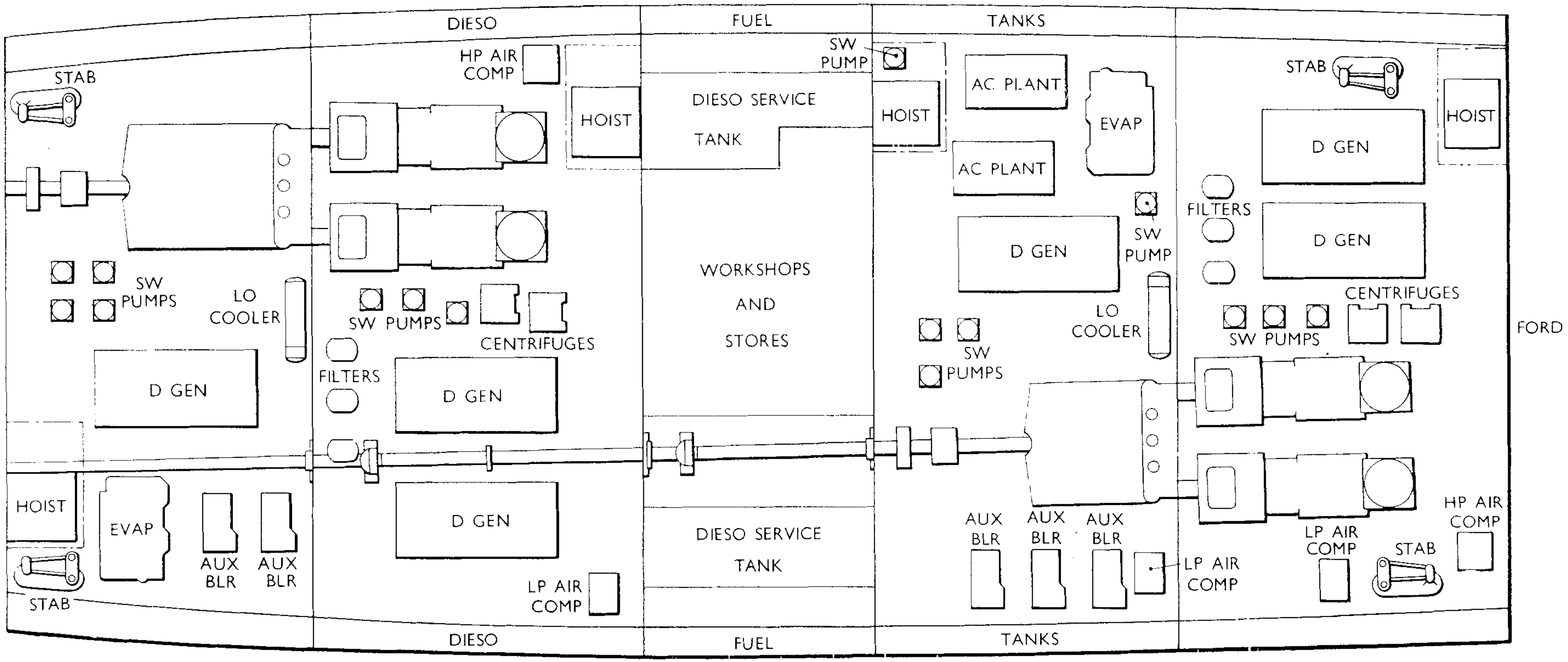

FIG. 9—SKETCH PLAN OF THE MAIN MACHINERY SPACES.

cheapest way. To meet this duty, five 6500 pounds per hour automatic auxiliary boilers are being fitted, a maximum of four being used at any one time.

Summing up, the domestic services are to be powered thus:

(a) Galley — electric
(*b*) Laundry — electric
(*c*) Winterization — electric
(*d*) L.O. centrifuge heaters — electric
(*e*) Ventilation heating — steam
(*f*) Evaporators — steam
(*g*) Domestic calorifier — steam

The relative sizes between the auxiliary boilers and the Diesel generators can be seen in the machinery layout drawing shown in FIG. 9. Each unit generates about the same amount of power and the Diesel generator is seven times as expensive, both in first cost and in maintenance costs. From both size and cost, it can be seen that the auxiliary boiler is still a very attractive alternative to the Diesel generator as a provider of heat. Every effort is being made in this ship to improve the steam and drain system by specifying all-welded pipes and other technical advances already proven in submarines.

Under the most arduous conditions, six Diesel generators will be required with one stand-by, the eighth assumed to be down for maintenance. Normally at sea four generators will be sufficient, and in harbour two or three will meet the load depending on the circumstances. The Diesel generator is being provided as a module complete with heat-exchangers, silencers, automatic watch-keeper, and starting arrangements all enclosed in an acoustic hood. The hood is sized so that a top-overhaul can be carried out inside it.

Air-conditioning System

Seven 1.8 million BTU per hour plants will be fitted in the ship, two being situated in the forward gearing room. Six of these plants will be required to run simultaneously when the ship is in tropical waters. Associated with these plants is a chilled-water system and an array of air-treatment units.

There is also a hot-water system, completely separate from the chilled-water system, which supplies water to heating elements in the air-treatment units. This water is heated by calorifiers situated in the gearing rooms and the system is brought into use in temperate or arctic waters.

Machinery Removal

The final layout of the machinery spaces is illustrated in FIG. 9. A repair-by-replacement policy has been applied throughout. Many units can be removed complete. The main exceptions to this are the gearboxes, power turbines, evaporators, and air-conditioning plants. Rotating elements of the former two (except the main wheel of the gearing) and sub-assemblies of the latter two can, however, be readily removed and replaced.

In order to implement this policy, there is a large removal trunk from each machinery space leading up to the side of the hangar. Permanent rails carrying a trolley are fitted across each machinery space to serve these removal trunks, and an overhead rail system is arranged to serve the permanent rails. The removal procedure for the outboard Diesel generator in the after engine room is as follows:

> Large doors at the end of the enclosure are opened; the Diesel is lifted from the enclosure, turned, lifted over the shaft, and lowered onto a trolley; this trolley is run across to the trunk where it is moved onto a lift platform

and thence up to the side of the hangar. It is then moved into the hangar where the trolley wheels are exchanged for rubber wheels for further movement onto an aircraft lift and thence onto the flight deck. The aircraft crane can lift the Diesel (which is the heaviest machinery lift) onto a dockside or lighter.

The gas turbine change-units are removed and replaced in a similar manner. A turbine change-unit is carried in each engine room to enable an engine change to be effected at sea without breaking into the hangar.

Bilge Pumping and Cleaning

Eductors are fitted in each machinery space for clearing large quantities of water. Small eductors are fitted for clearing clean water. As the bilge at the centre line on the inner bottom is higher than at the wings, a sump is fitted on each side of the machinery space, and a bilge pump is fitted in each space. Both the bilge pumps and eductors take a suction from the sumps. The bilge pumps discharge through an oil/water separator; the water is discharged over the side and the oil is collected in a sullage tank. The dirty oil in the sullage tank can be used for firing the incinerators.

Fixed pipes are fitted through the ship's side to enable a tank cleaning vessel to connect to the outside of the ship. Flexible hoses can be connected to the inboard end of the pipes for use when cleaning Dieso tanks and bilges. This is to avoid dragging long dirty hoses through the ship.

Machinery Space Ventilation

Each machinery space has two supply fans and two exhaust fans. Supply air is trunked into all areas of the compartments concerned and the exhaust fans clear the air from the tops of the compartments and discharge it up the funnel casing and out at the top. The Diesel generator and power turbine enclosures receive their air from this system and vent back into the compartment. The gas generator enclosures have their own special fans and have trunked air. There are cross-connections between the various fans to ensure that the failure of one fan does not cause major overheating of any particular piece of equipment. The exhaust fans are fitted with filters on their inlets. The main gearbox vents are led over the side into open air. It has been an objective of the design to keep the machinery space and uptake space atmosphere as clear of oil as possible. With the very hot uptakes, there is a higher risk of fire in the uptake spaces than in older ships. As an additional precaution, the bellows in the exhaust trunking have a secondary containment with remote indication of a gas leak through the bellows.

Under closed down conditions, the exhaust fans are stopped and the supply fans are run on recirculation through machinery space coolers; the gas-generator fans continue running. A panel, fitted in the SCC and containing the running lights and starting and stopping arrangements for the fans, enables the necessary change-over of the system to the closed-down condition to be made. The change-over flaps are operated locally. As a general rule throughout the ship, ventilation air is taken in on the port side of the ship and discharged from the starboard side.

Layout

Compared with the steam ship, the general accessibility for operation and maintenance should be better. The evolution of modelling techniques has greatly assisted the drawing offices in producing the optimum layout. In this ship, however, it has been a disappointment to see how the deckheads of the main machinery compartments have become congested with supply and exhaust ducting, removal rails, and cabling.