THE EVOLUTION OF WARSHIP MACHINERY 1945–1990

BY

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ABSTRACT

Post-war warship machinery development has been driven by the need to increase endurance, improve reliability and reduce complements. The main elements have been:

(*a*) higher steam conditions and design for economy at cruising speed;

(*b*) gas turbine main engines and electronic control;

(*c*) electric drive.

The Background

The background to the post-war revolution was the long period, between the two world wars, when virtually no development took place. The reasons for this dead period are vividly explained in Sir Louis Le Bailly's fascinating book *From Fisher to the Falklands*[1]. One valiant attempt was made to improve the design of destroyer machinery: HMS *Acheron* was fitted with steam machinery of relatively advanced design (500 lb/in^2, 700°F) in 1928. The machinery had no development testing on shore before being installed in the ship and she was expected to run as a fully working member of her flotilla. Inevitably there were problems—mainly with leaking joints and turbine vibration. For much of the time she was limited in speed to 20 knots (against 33 knots for her sister ships) and the machinery needed frequent repairs. The result was that development of all kinds was judged to be dangerous and self-defeating and none took place. Hence, in the second world war, our ships were seen to compare most unfavourably with their counterparts in the United States Navy, in terms of reliability, weight and space, and fuel consumption.

It was against this background that a group of Engineer Officers was assembled to analyse the problem and set in train the work necessary to recover lost ground. Prominent in this group was Cdr George Raper, later Vice-Admiral Sir George and a very distinguished President of this Institute.

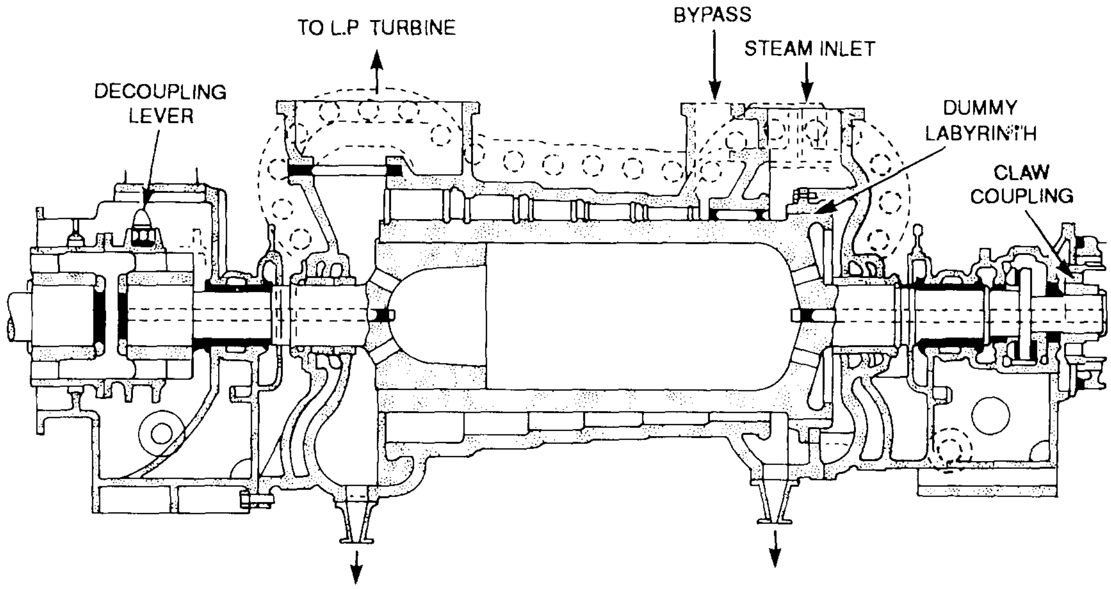


FIG. 1—A TYPICAL PARSONS IMPULSE REACTION HP TURBINE

It is worth a moment to look at where they were starting from. A typical World War II RN destroyer would have had two Admiralty 3-drum boilers producing steam at 350 lb/in^2 and at a temperature of 550°F. The steam turbines would have been HP and LP Parsons impulse reaction turbines. The HP turbine (FIG. 1) may have had a Curtis wheel at the inlet end, would have been hollow, with a dummy piston (to balance thrust), and it would have been made in two parts with a shrunk joint. The LP turbine (FIG. 2) would be dual flow with the astern turbine (a Curtis wheel) mounted on one end. Single reduction gearing was used. Many of the main engine auxiliaries were driven by direct-acting steam reciprocating engines and there was practically no automation—boiler and condenser water levels were automatically controlled, but even these controllers were unreliable and the boiler room watch always included a water tender whose job it was to monitor the boiler water levels. Electric power was provided by d.c. generators and there was not much of it—perhaps 100 kW total installed capacity. Engine room complements were large. The philosophy prevalent at the time was that any spare parts which were needed should be manufactured on board using the ship's machine tools and they were 'made to fit'. Hence the modest steam conditions, since only simple materials could be worked in most ships.

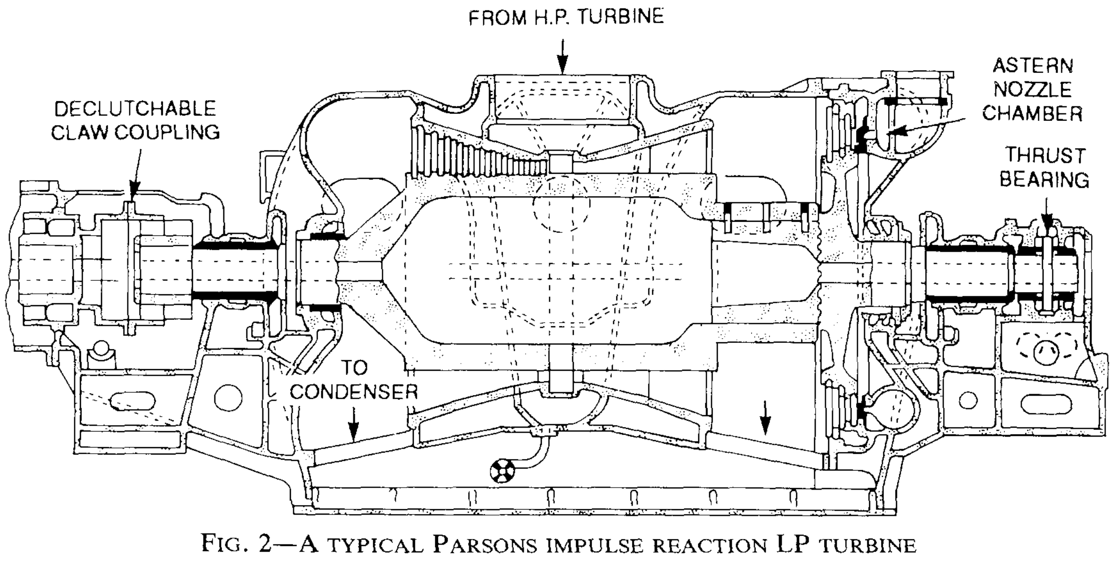


FIG. 2—A TYPICAL PARSONS IMPULSE REACTION LP TURBINE

High maximum speed was always a requirement for destroyers which were, in some sense, the cavalry of the Navy. The machinery was high powered, demanding in manpower, of indifferent reliability and occupied a large proportion of the hull. It was also relatively inefficient at the cruising powers at which the ships spent most of their lives.

The Darings

The first step was to order the machinery for the DARING Class of destroyers which were conceived in 1945 (FIG. 3). The machinery selected for these ships was essentially the same as that which had powered the US Navy destroyers during the second world war. Steam pressures and temperatures were raised and control of steam temperature, so that it could be reduced when manoeuvring, was introduced. Two designs of boiler, three of steam turbine and three of double reduction gearing, were ordered. New designs of rotating auxiliary machinery were fitted. Much of the machinery was subjected to prolonged shore testing at Wallsend, the PAMETRADA headquarters. Some of the ships had a.c. electrics.

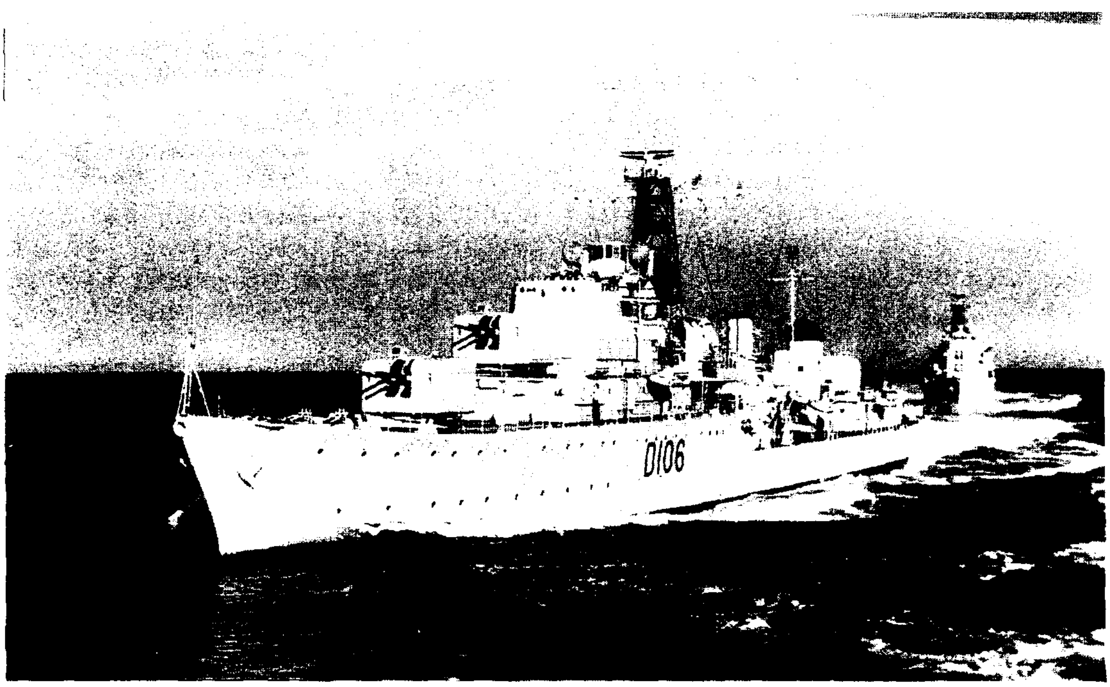


FIG. 3—A 'DARING' CLASS DESTROYER, HMS 'DECOY'
J. M. Maber collection

There is not time, in a short review like this, to discuss all the variants which were assessed in the DARING Class. The testing of the machinery at PAMETRADA was exceptionally thorough and the resulting data base was of inestimable value in developing future designs. In service, steam leakage and marginal water-making capacity were among the problems. Indeed, this was the time when the lives of a whole generation of naval engineers were dominated by water making, water quality and water storage capacity. Nevertheless the DARING Class ships constituted an indispensable first step on the road to producing modern propulsion plants for the Royal Navy. They posed questions that many, including the shipbuilders, found it difficult to answer and they earned the reputation of being challenges to be overcome rather than solutions to the Navy's problems. Nevertheless they taught us much and without them the changes that followed would have been immeasurably more difficult.

YEAD 1

While the DARINGS were being built and evaluated, a study was started to produce a new design of standard machinery based on a requirement for 30 000 shp/shaft. This design, known as the Yarrow—English Electric-Admiralty—Design (YEAD 1) was built and extensively tested by PAMETRADA. Before the evaluation of YEAD 1 was complete the Naval Staff issued a requirement for a North Atlantic Convoy Escort, the first of which became HMS *Whitby*. In the event YEAD 1 machinery was never fitted in a warship. Many regarded this as a great pity because it was a compact state-of-the-art design which received exceptionally thorough evaluation during shore testing.

The Whitbys

The WHITBYS constituted the first of the post-war designs of naval frigates. The requirements were demanding. Greatly increased endurance—the wartime destroyers could not cross the Atlantic without refuelling—and a 25% reduction in machinery and fuel weight and space. The latter was required in order to make room for an increased weapon fit. Faced with a challenge of this size, the Engineer-in-Chief's department set up a design agency under the management of Yarrow shipbuilders—the Yarrow Admiralty Research Department, now known as YARD and long since totally independent of Yarrows. YARD conducted a number of design competitions to produce the major components, but from the outset it was obvious that in order to get the compactness which was called for it would be necessary to adopt high steam pressures and temperatures and higher rotational speeds. This in turn led to the abandonment of the shrunk joint HP turbine for a solid all impulse turbine rotor of English Electric design, controllable superheat boilers with tight tube spacing, double reduction gearing and lightweight, compact, rotating auxiliaries. These changes then led to the use of alloy steels which could not be easily worked on board and

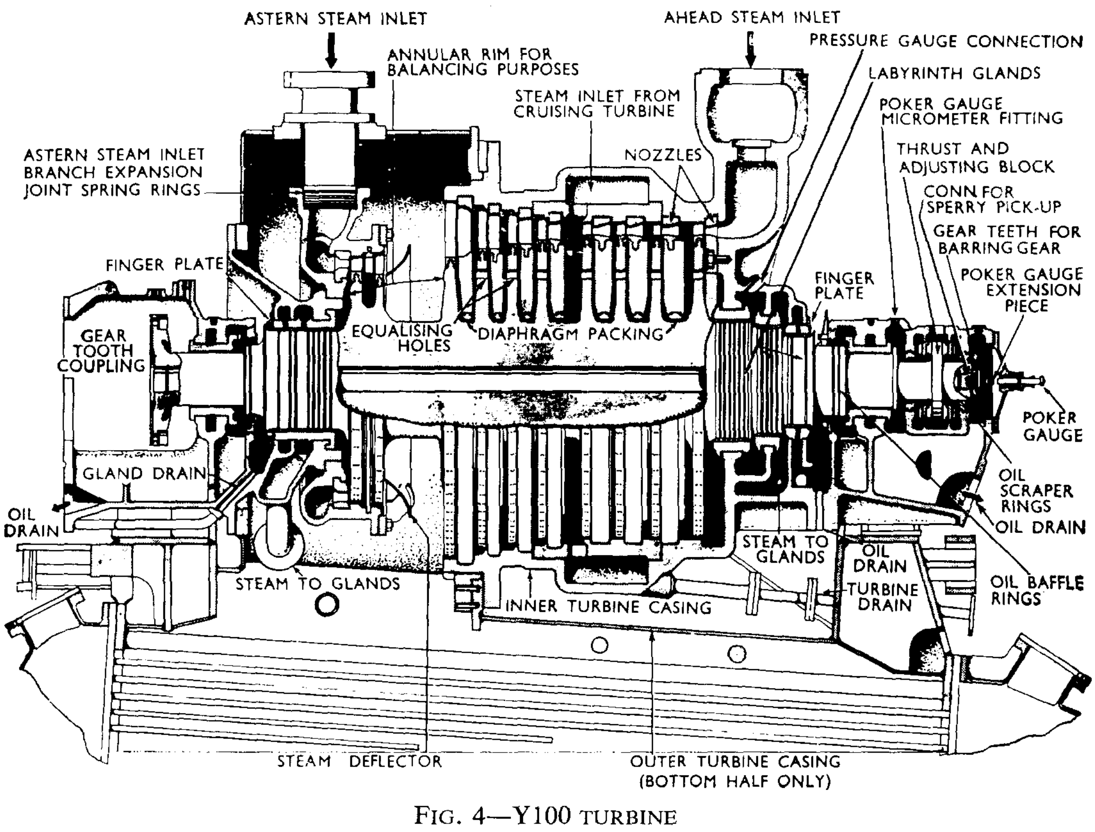


FIG. 4—Y100 TURBINE

so spare parts had to be supplied in finished form: this led to the introduction of tolerances on all components—a change in design and manufacturing practice which caused enormous problems. Electrical generating capacity was growing and from now on all ships had a.c. systems despite the grave misgivings of the old guard.

It will be seen that this machinery design, known at the Y100 (see FIG. 4), represented a very bold departure after the lost years since 1920. The revolution that was launched then has had profound effects on naval machinery ever since, and such was the quality of the original concept that after two further modifications the design is still at sea in the LEANDER frigates of the RN and the LEANDER derivatives of the Indian, Australian, New Zealand, South African, and Chilean Navies.

At first the new design caused serious operator problems. The compactness, higher rotational speeds, higher temperatures and pressures and smaller system capacities all meant that the margins for error were smaller than those in the older machinery on which most of the operators had cut their teeth. Gradually, experience and familiarity led to the recognition that this was a classic set of machinery; rugged, economical, compact and maintainable. The main engine auxiliaries were the biggest continuing cause for concern, and the long and complicated story of these is worth a paper on its own.

The studies embarked on at the time of the Y100 design have affected all subsequent naval machinery installations. An analysis of World War II destroyer operations revealed that they spent at least 80% of their life at cruising speed or less: and because of the shape of a destroyer's power speed curve this meant that 80% of their life was spent at less than 20% of the installed power (see Fig. 5). The understanding of these facts was to have a profound influence on the future development of frigate machinery. It became obvious that the use of full power as the design point could no longer be justified: the overriding need was to reduce fuel consumption at the designated economical speed. In the case of the Y100 machinery a cruising turbine was included in the initial design but problems with the associated clutch caused the cruising turbine to be removed. At the same time it was appreciated that what mattered was not machinery weight alone, but the weight of machinery plus fuel to meet the required speed and endurance.

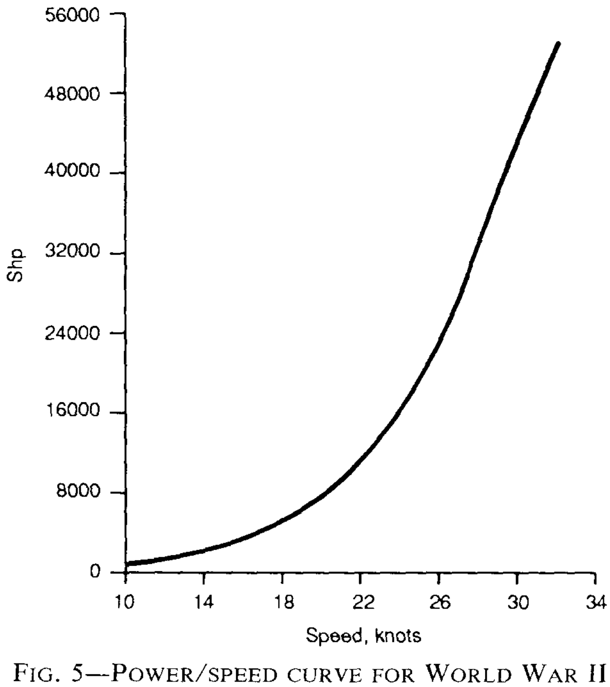


FIG. 5—POWER/SPEED CURVE FOR WORLD WAR II DESTROYER

Another change embodied in this machinery was to have important long-term effects. In order to achieve the compactness called for by the Staff Requirement, the boilers were made much smaller than formerly and steam temperature was controlled by dampers which diverted the gas glow (FIG. 6). Compactness meant tighter tube spacing: this led, in turn, to increased susceptibility to fouling and hence increased frequency of gas side cleaning. In spite of the introduction of water washing of boilers, which improved the effectiveness of external cleaning and speeded it up, fouling of boilers continued to be a major constraint on operational availability. Eventually,

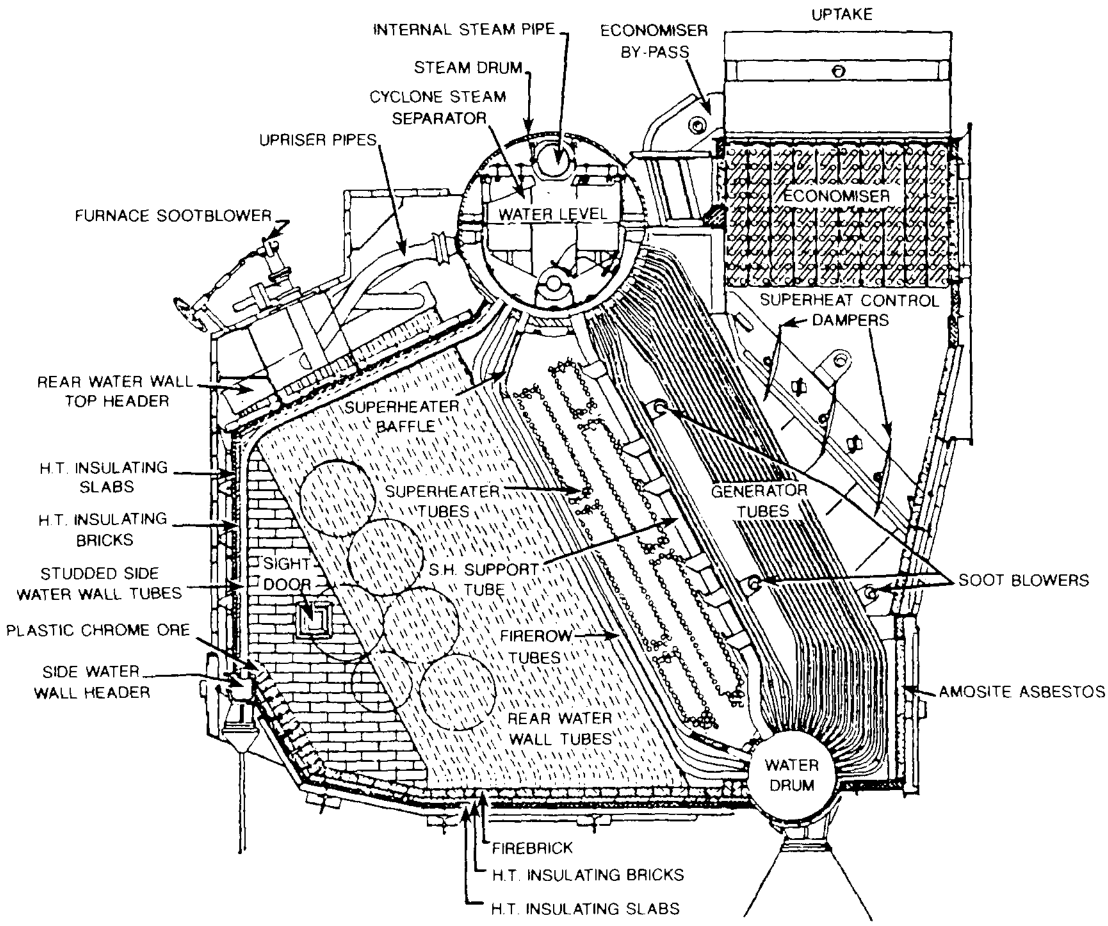


FIG. 6—Y100 BOILER

some 20 years after the introduction of Y100 machinery, all boilers were converted to use diesel fuel and Admiralty Furnace Fuel Oil (FFO) disappeared from the Fleet.

One other major effect of the introduction of the new machinery was the requirement for increased training for the operators and maintainers. Standards which had previously been acceptable were sometimes cruelly exposed by the new machinery and extensive pre-joining training was introduced for the engine room crews of the new ships.

The WHITBY/Y100 design brought the Navy up to date with a single leap. The machinery and systems were refined in two successive exercises (LEANDER Class, FIG. 7, and improved LEANDER Class, FIG. 8) which led to simplification and improvement of system designs, automation and remote operation of boilers and main engines, increases in electrical generating capacity, redesign of auxiliary machinery and systems and so on. At the same time there was pressure to improve availability and new procedures for the planning and implementation of preventive maintenance were introduced, refit intervals were extended and the control and supply of spare parts were reorganized.

If I have dwelt at some length on the evolution of the Y100 machinery and its consequences for men and material alike, it is because the introduction of this new machinery was the spring which has powered all subsequent changes in naval frigate machinery design. Many of those who were closely involved with this development went on to take the lead in the subsequent introduction of gas turbines and high-speed diesel engines for naval use. For those who were involved at the time the excitement was almost palpable. Risks were taken but they were always calculated and the Navy was singularly fortunate to have the men to meet the challenge at the right time.

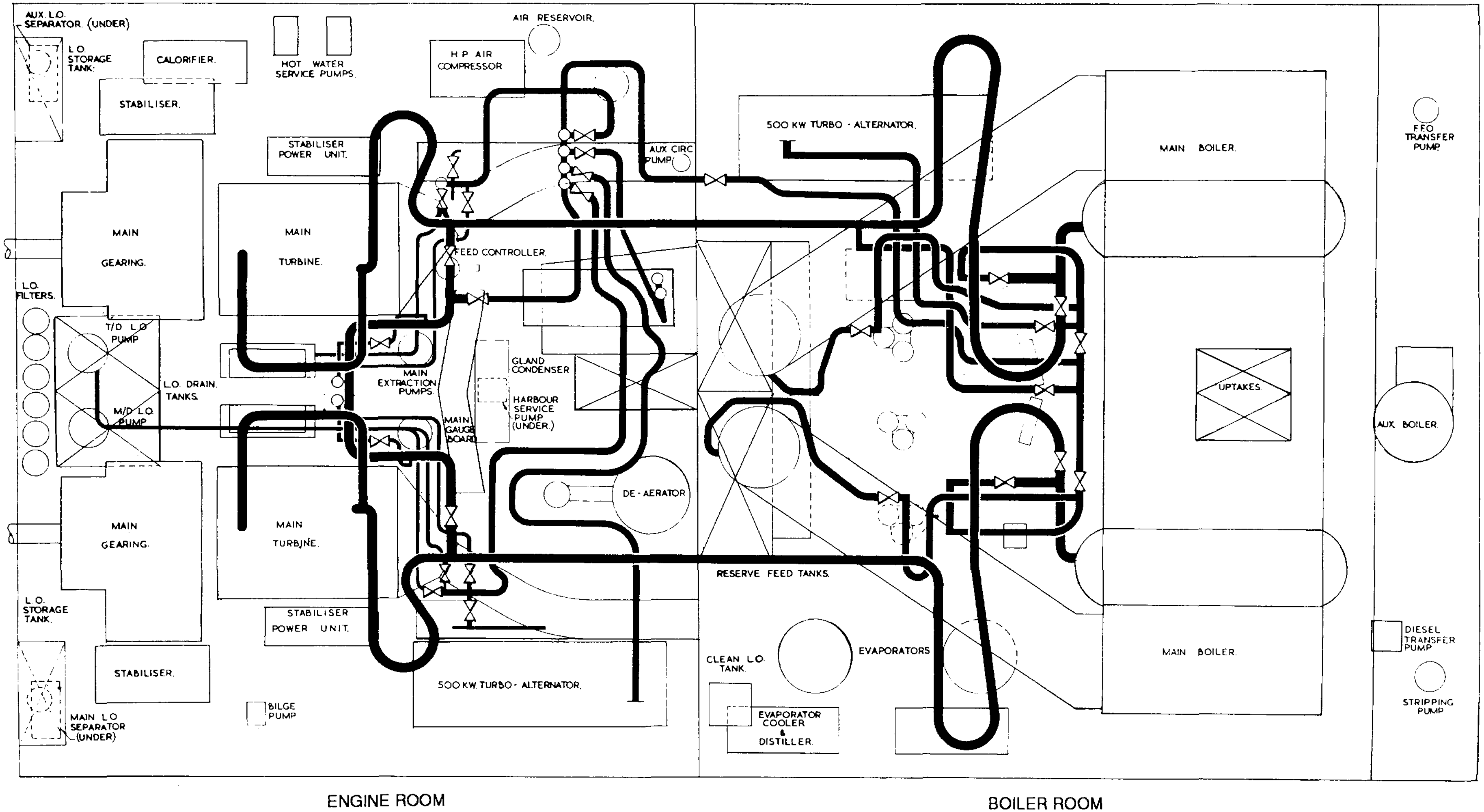


FIG. 7—'LEANDER' CLASS SUPERHEATED STEAM SYSTEMS

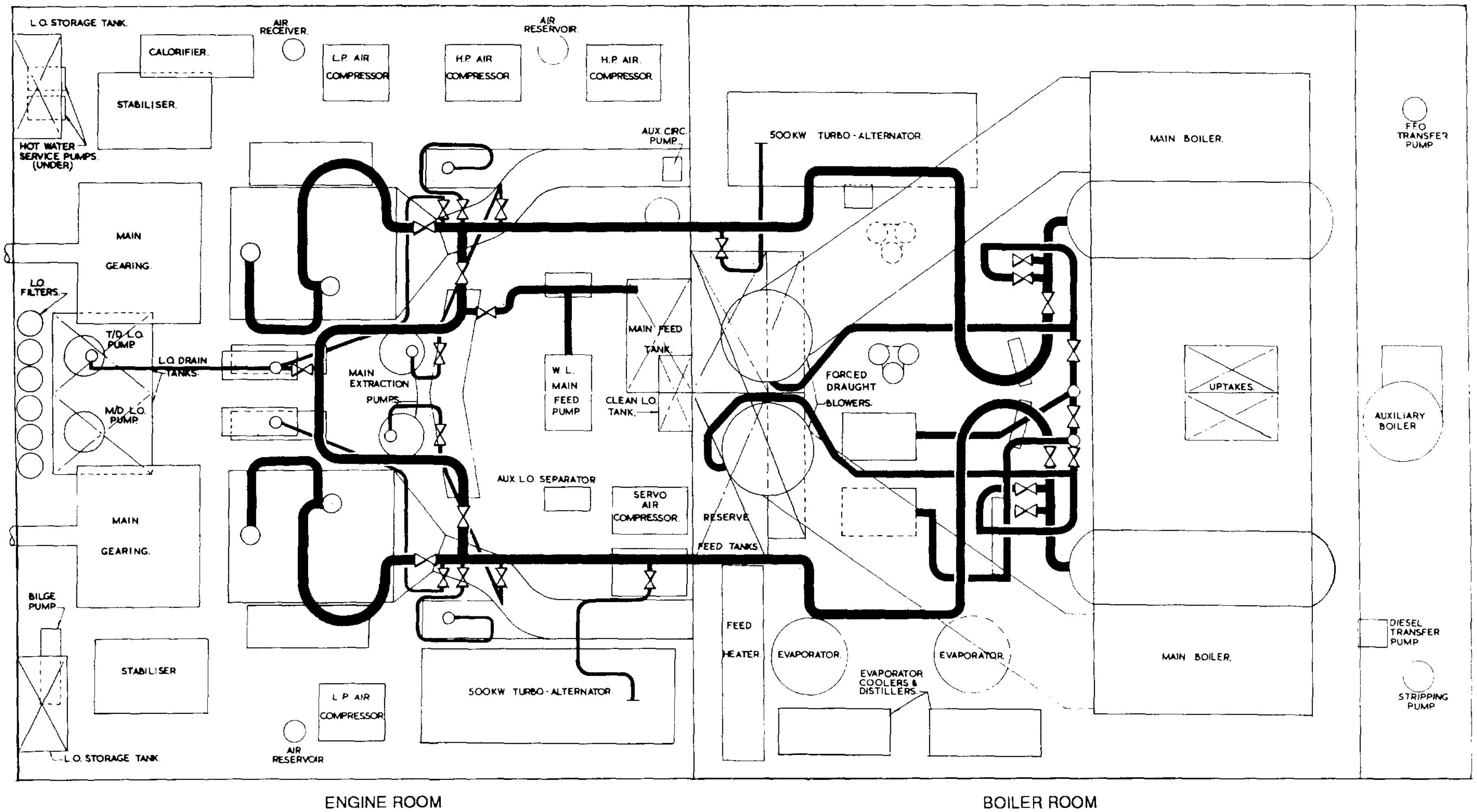


FIG. 8—'IMPROVED LEANDER' CLASS SUPERHEATED STEAM SYSTEMS

Subsequent machinery development has been heavily influenced by the recognition of the requirements for efficiency at low power and by the availability of gas turbines.

Gas Turbines

Trials of gas turbines in ships started very soon after the war, initially in MTBs and fast patrol boats. Increasing confidence in their reliability soon led to consideration of their use for frigate propulsion. Gas turbines, certainly those of the era of which I speak—the late 1950s—were compact, high powered, thirsty and relatively short lived. It did not take long for people to realize that they offered a very attractive means of providing the high power which our ships needed for relatively short periods.

However, this was the age when nuclear weapons dominated all military thinking. The gas turbines used by the Fleet were required to have excellent shock and blast resistance and to be gas-tight under the most exacting operating conditions. As a result the original concept of a lightweight, aircraft-style gas turbine was gradually modified to produce a robust, heavy machine for which repair in-place began to appear appropriate. Nevertheless the AEI G6 gas turbine—for thus it was designated—was to form the basis for the design of two important new classes of ships.

The County and Tribal Classes

The first of these was the COUNTY Class. These ships were designed to be fitted with a long range anti-aircraft missile system (Sea Slug). They were large (5440 tonne) destroyers—really closer to a wartime cruiser—which needed 60 000 shp. The plant which was produced consisted of combined steam and gas turbine power (COSAG) on two shafts.

Each shaft set of machinery consisted of one boiler producing steam at the relatively advanced conditions of 700 lb/in^2 and 900°F, a cross compound steam turbine set of 15 000 shp and two G6 gas turbines of 7500 shp each. A reversing steam turbine was fitted to the after end of the LP turbine and the gas turbines were provided with a manoeuvring mode of drive, which meant that they could be used to get the ship to sea, driving ahead or astern through hydraulic couplings, at very short notice in an emergency—another of the requirements which developed from the perceived danger of nuclear attack (FIG. 9).

At the same time that the COUNTY Class destroyer design was being developed, a requirement arose for a new class of simple, low manpower, frigate. This class became known as the TRIBAL Class, the first ship being the *Ashanti*.

In this case a ship of 2500 tonnes was required and the propulsion requirements were for a single shaft set of 20 000 shp in total. The power plant chosen was a single boiler, producing steam at the, by now modest, condition of 500 lb/in^2 and 700°F, driving a single cylinder steam turbine of 12 500 shp with one G6 gas turbine driving into the same double reduction gearbox. Again the gas turbine was provided with manoeuvring drive so that the ship could be manoeuvred on gas turbines alone. The boiler and turbine were close derivatives of the Y100 design.

In both the COUNTY and the TRIBAL Classes the basic philosophy was the same: lower the maximum power of the steam turbine so as to bring the maximum steam power closer to the power needed for economical speed, and hence improve the efficiency of the plant at lower speed. At the same time advantage was taken of the second power source to limit and simplify the equipments and systems—e.g. one boiler per shaft, reduced vacuum at full steam power, etc. Both classes were designed for nuclear war and this led to the first large-scale use of remote and automatic controls. Both classes were fitted with gas turbine alternators as well as steam-driven ones.

The adoption of gas turbines as a main propulsion power source was a major step and one which, after some initial teething troubles, was totally vindicated. The gas turbine and the associated reversing gearboxes were extensively tested ashore and despite their novelty very few serious problems were encountered with them. The gearboxes for these ships were by far the most complex the Navy had ever specified and their size was only controlled by the adoption of high load factors. The adoption of the synchro-self-shifting (SSS) clutch was critically important to the evolution of this machinery. This highly ingenious equipment used a synchronizing device to bring the two halves of a coupling to the same speed and then engaged, and locked, a positive drive. These clutches can be built to run at any power and any speed. They suffer from none of the shortcomings of magnetic, centrifugal, friction or fluid clutches. The successful development of the SSS clutch has made possible the compact multiple drive gearboxes used in virtually every subsequent warship design. They are now standard equipment in thousands of power plants, including hundreds at sea.

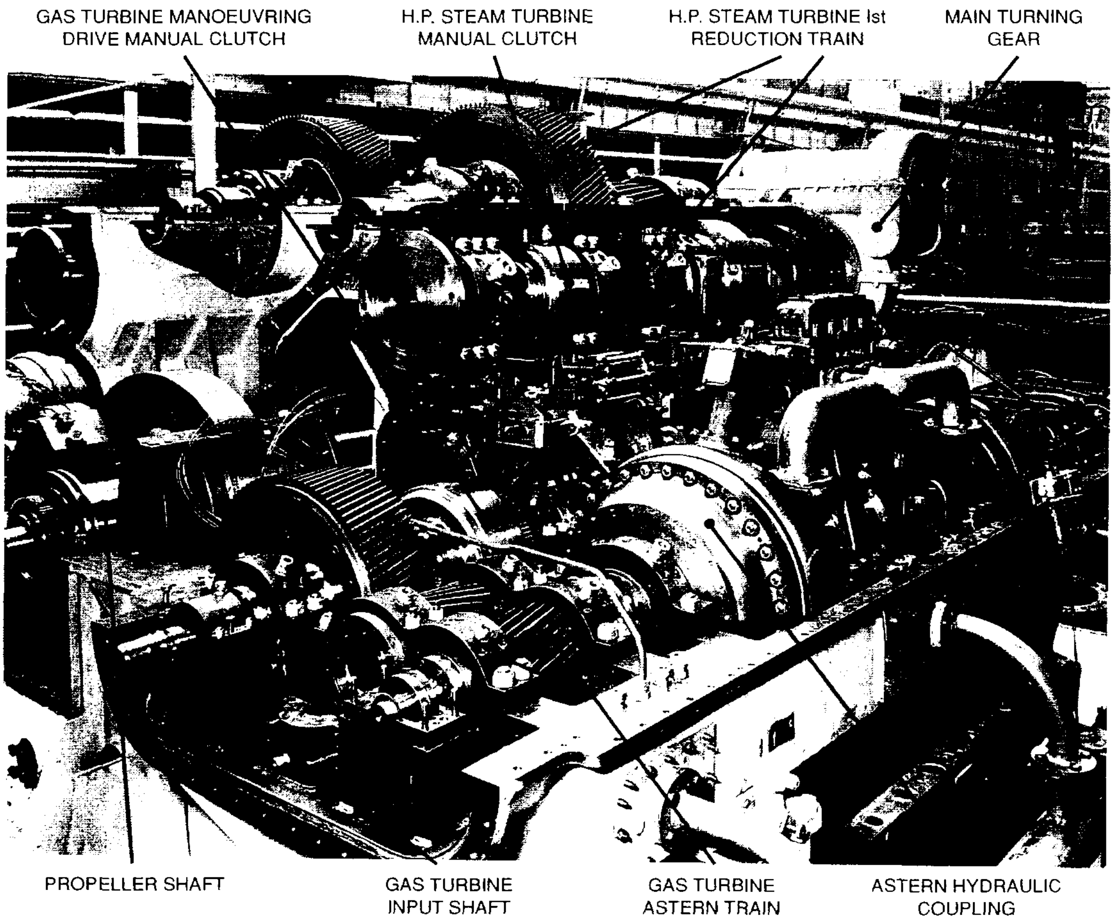


FIG. 9—'COUNTY' CLASS GEARBOX

Although the G6 engines and the main engine gearing in these ships performed well, the steam plant continued to pose problems. A spate of alarming and potentially disastrous boiler explosions, usually occurring when flashing up a boiler or during extensive periods of very low power, was eventually overcome by new operating procedures. In order to achieve the desired remote control of the boilers new combustion equipment with very wide range burners had to be developed. The high gear loading led to the adoption of a new extreme pressure (EP) lub oil which did not like salt water. Extensive corrosion in white metal bearings resulted, leading to machining type failures in both main engines and steam driven auxiliaries.

Partly as a result of the problems mentioned above, the engine room complements of these two classes of ship remained obstinately high. Even so the maintenance requirements of the steam plant meant that these ships only achieved the required availability with difficulty.

Nevertheless, if the TRIBAL and the COUNTY Classes did not acquire the reputation for enduring excellence enjoyed by the WHITBY/LEANDER Class, they were critical to the evolution of the future destroyer/frigate force. In particular, they made the reputation of gas turbines as compact and reliable main engines, and the evolution of the combining gearbox, with its new SSS clutches, was a major engineering milestone.

Aircraft Gas Turbines

Whilst the G6 was entering naval service in the TRIBAL and COUNTY Classes, lightweight gas turbines in the form of the Bristol Siddeley Proteus were giving impressive results in the BRAVE Class patrol boats. In these ships, a full refit by replacement policy was adopted and the only modification to the engines involved some material changes to cater for the marine atmosphere. The implications of the success of these engines were obvious. Britain possessed a wide range of aircraft gas turbines covering power from a few hundred horsepower up to nearly 30 000 shp. All of the engines had undergone very extensive—and expensive—development, many hundreds had been built and many thousands of hours of service had been achieved. Since the development of new gas turbines exclusively for the RN was out of the question because of the high cost, ways had to be found to use aircraft engines.

The New Aircraft Carrier (1960s)

At about the time that the COUNTY Class ships were entering service (the early 1960s) a major thrust of Naval procurement was to replace the front line aircraft carriers *Ark Royal, Eagle* and *Victorious.* A project team was established and the design was far developed before it was cancelled in the 1966 Defence Review, which announced the Government's intention to close all overseas naval bases and to end our worldwide naval presence. It is of interest to note that these aircraft carriers would have been all-steam ships and, in a sense, they represented the last throw of the all-steam lobby. Although there was bitter disappointment at the cancellation there was also in some ways a sense of relief, for the size of the ships had grown during the design phase and the margins—of propulsion power, generating and air conditioning capacity and so on—had all but disappeared at the time of the Defence Review, which deemed that the Royal Navy was to have no more aircraft carriers. This last point became important in the light of future events.

HMS 'Bristol'

To provide air defence for the new carriers, a new class of destroyer was designed, the Type 82. The first of these ships, HMS *Bristol* was ordered some time before the 1966 Defence Review, as a lead ship for a considerable class. She was completed and entered service, and has recently been decommissioned. The *Bristol* was another combined steam and gas turbine design (COSAG) but this time, in place of the G6, a true aircraft-derivative gas turbine was fitted, and HMS *Bristol* had one Bristol Siddeley (as it then was) Olympus fitted on each shaft in conjunction with a single cylinder steam turbine of 20 000 hp (FIG. 10).

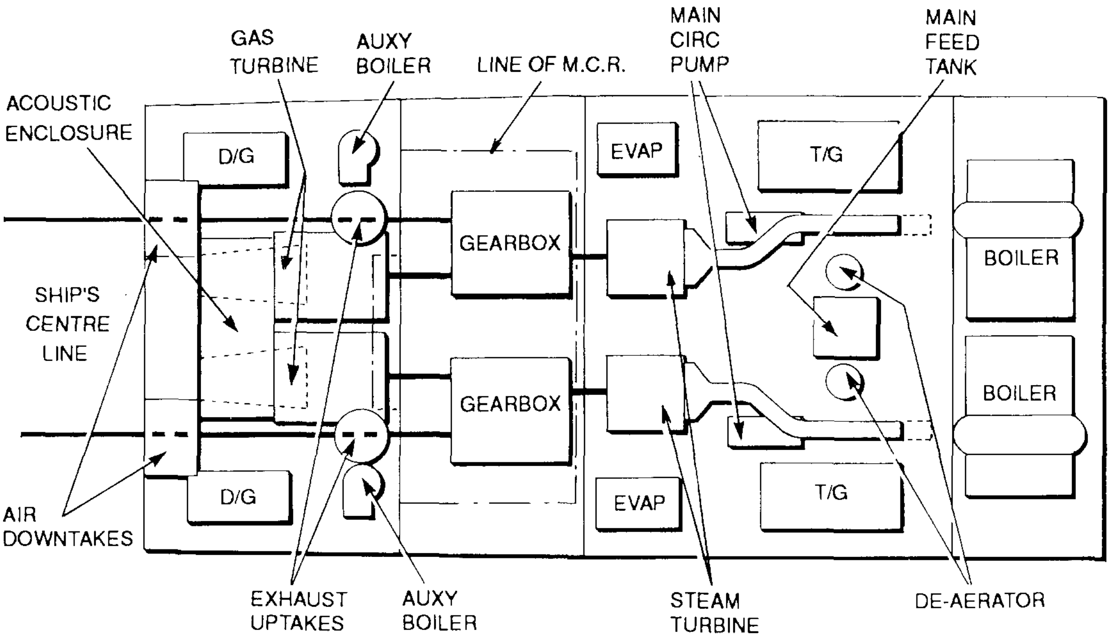


FIG. 10—HMS 'BRISTOL' MACHINERY ARRANGEMENT

In machinery terms the ship compared in many ways with the COUNTY Class—and suffered from many of the same problems. However the Olympus gas turbines were highly successful, and when the ship suffered a very serious machinery space fire she ran on for several months on gas turbines alone until the repairs to the steam machinery could be undertaken. Only one ship of this class was built.

HMS 'Exmouth'

The idea of adapting aircraft engines to propel major units of the Fleet—and hence of adapting aircraft engineering practice for the support of the Fleet—was so radical that those concerned realized that a full scale demonstration would be necessary if the Admiralty Board and the politicians were to be persuaded. Eventually, after much politicking, lobbying and persuading—enough to provide the subject matter for a very long book—approval was gained to convert HMS *Exmouth* to all gas turbine propulsion.

Exmouth was one of a small class of steam frigate, built at the same time as the WHITBYS. Conceived as cheap, single shaft ships with two boilers and one 15 000 shp WHITBY turbine, they had never quite succeeded in the escort role for which they had been provided.

The same immutable rules applied to *Exmouth* as to any other frigate: the great majority of her life would be spent at a very low proportion of full power; the power/speed curve would be very steep at the upper end; there was neither the space nor the resources to maintain gas turbines onboard.

The machinery installed in HMS *Exmouth* is shown in FIG. 11. Cruising power was provided by two Proteus engines while high 'boost' power was provided by a single Olympus gas generator which exhausted into a specially designed power turbine. Manoeuvring was achieved through a controllable pitch propeller.

The *Exmouth* trial showed beyond any doubt that aircraft type gas turbines were entirely suitable as main propulsion machinery for the Royal Navy. The immense development costs of new aircraft gas turbines were aimed at, among other things, promoting reliability. And so it proved in practice. Good design was needed to keep the salt out. Special mounting arrangements were necessary to absorb shock and the engines would need to be screened by blast-proof containment. Nevertheless, at a stroke fuel consumption was reduced, on-board maintenance was cut, availability was increased and the working conditions in the machinery space were improved beyond imagination.

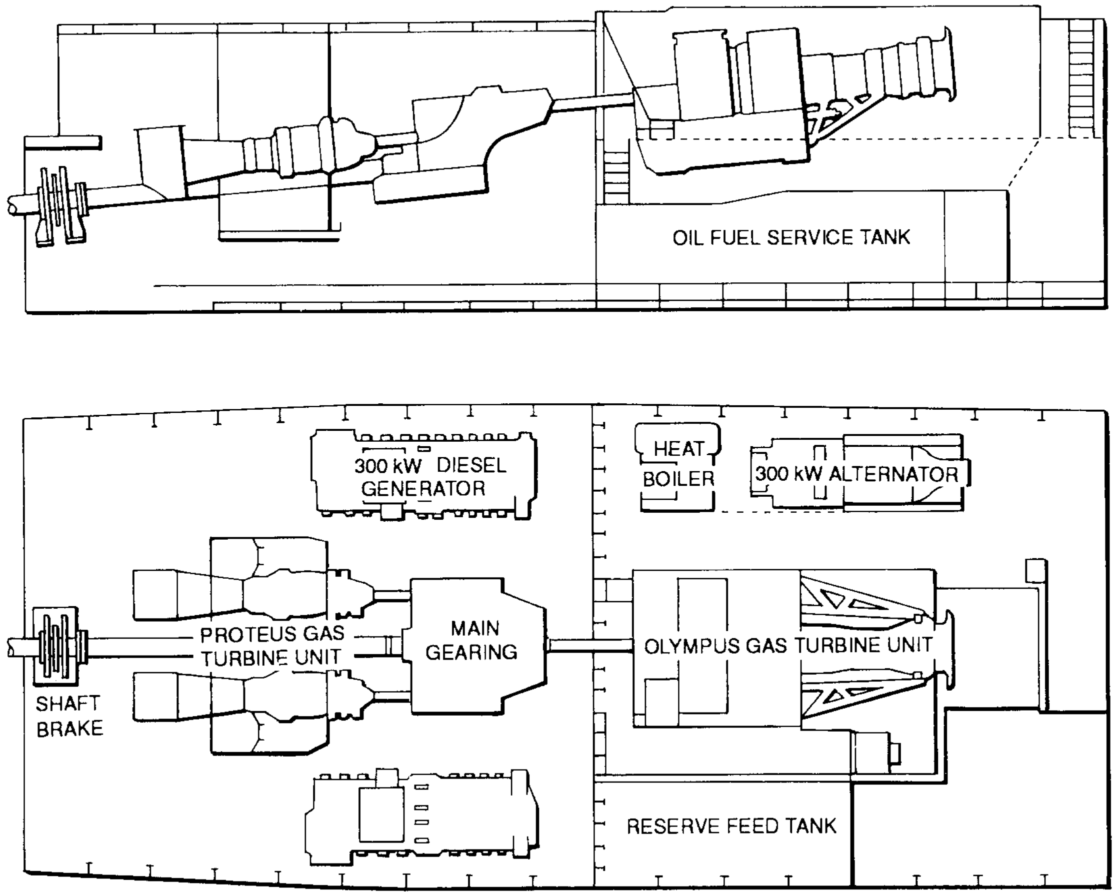
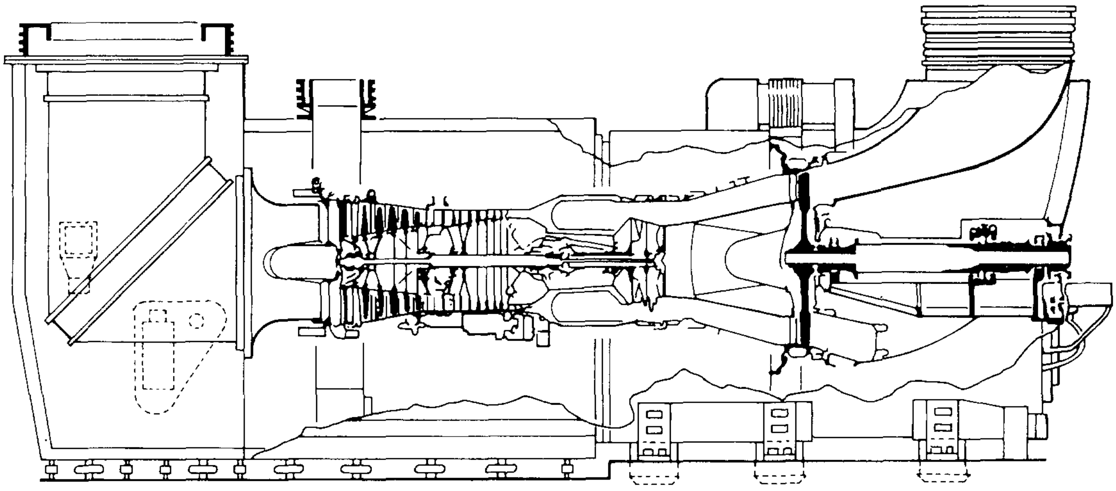


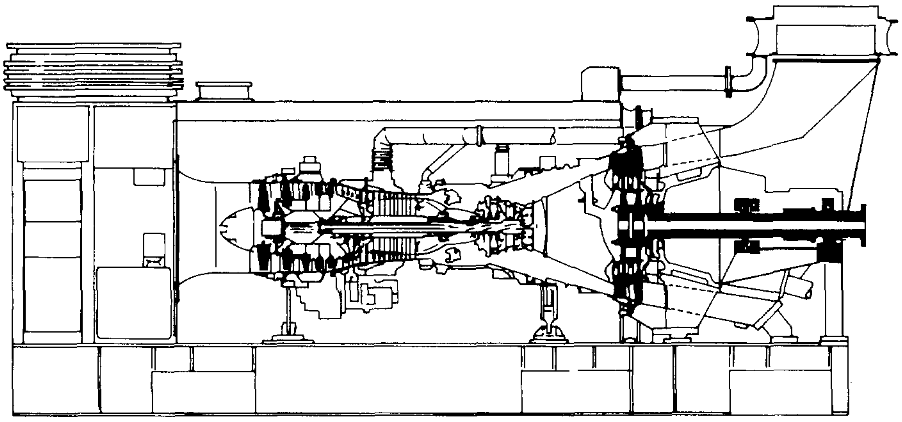
FIG. 11—HMS 'EXMOUTH' MACHINERY ARRANGEMENT

COGOG—Types 42, 21 and 22

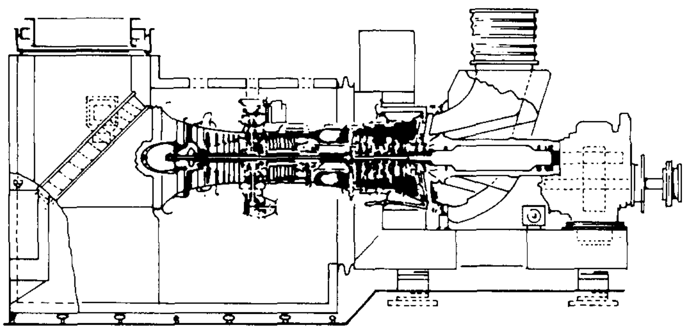
The *Exmouth* trial vindicated to the full the claims of the gas turbine lobby and the fate of steam in surface ship design was effectively sealed. Following the cancellation of the aircraft carrier programme, the air defence of the Fleet assumed even greater importance. The major weapon system was Sea Dart, installed in HMS *Bristol*, but this ship was far too big, and too expensive, to be used as the model for the new ships. The design which evolved, the Type 42, was an all gas turbine destroyer using marinized aircraft gas turbines. The ships were smaller than the *Bristol*, less comprehensively armed and with a smaller complement. For high power the Olympus was selected. For cruising power the Navy chose the Rolls-Royce Tyne engine (FIG. 12). Specified cruising speeds were rather higher than formerly and the Navy sought a more powerful and more efficient engine than the Proteus. The Tyne fitted the bill although the engine needed extensive modification. Not only was it necessary as in the Olympus to change many materials, but also the power turbine had to be redesigned. In the aircraft engine the power take-off was coupled directly to the LP turbine and compressor: to match a destroyer's power/speed curve, a free power turbine was required. It is notable that when the Navy were considering the use of the Tyne engine they asked BEA, the main operators of the engine in



OLYMPUS TM3: Max Power 21 MW; Length 9.17m



SPEY SM1: { SM1A: Max power 14 MW; Length 7.502m
SM1C: Max power 19.5 MW; Length 7.502m



TYNE RM1: { RM1A: Max power 3.2 MW; Length 5.56m
RM1C: Max power 4 MW; Length 5.56m

FIG. 12—ROLLS-ROYCE MARINE GAS TURBINE MODULES

the UK, for their views. They were told by one engineer that the Tyne had been, without reservation, the worst engine BEA had ever operated. As a result there had been an intensive effort and large expenditure to improve the reliability of the engine. During, and following the marinization of the engine, the Navy conducted extensive trials. In the end, for the Navy, the Tyne has proved to be highly reliable as well as efficient.

Following the decision to fit all gas turbine machinery in the Type 42 (SHEFFIELD Class) it was decided to specify the same machinery for the Type 21 (AMAZON Class), which was designated as a replacement General Purpose Frigate. This class is of particular interest because the Director General Ships of the day said that he lacked the resources to undertake the design, so the task was undertaken by a shipbuilder, the first time such a course had been followed for a front line ship this century.

The success of the Tyne/Olympus fit in the Type 21, 42 and, later, the Type 22 Class, as well as in the destroyers and frigates of the Royal Netherlands Navy and in the ships of the Japanese Maritime Self Defence Force, is now well known. Perhaps less well known is the revolution in the working conditions, training and employment of the engine room complements of these ships. The proof, if proof is needed, lies in the very long periods of continuous operation which they achieved in the wars in the South Atlantic and the Persian Gulf. Consider the case of the British Pacific Fleet in the second world war whose ships could only be committed to eight days on station in each month.

The commitment to gas turbine propulsion brought in its wake a whole train of subsidiary changes. How should electrical power be generated, fresh water be produced or spaces be heated in ships which did not have boilers for main propulsion? The Merchant Navy had faced the questions for many years but the circumstances and the conditions in warships were profoundly different.

In the TRIBAL and COUNTY Classes, and in the *Exmouth*, gas turbine alternators had been fitted as well as, in the first two classes, steam turbine alternators. The TRIBALS had the Allen 500 KVA gas turbo alternator. This was a complex high efficiency machine whose efficiency and output fell away very rapidly due to fouling of the compressors and heat exchangers; restoring the performance was a lengthy and expensive business. The COUNTIES were fitted with the Ruston TA gas turbo alternator. This machine was simple, rugged and reliable. It was also large for its output, its efficiency was very low and it compared very poorly with a high-speed diesel generator on a 'machinery plus fuel weight' basis. Accordingly, diesel driven generators were specified for the new ships. Strangely, surface ship experience with diesel engines in the Royal Navy has been very limited except for emergency and harbour duty engines. Two small classes of diesel powered frigates, the Type 41 and the Type 61, were built at the same time as the WHITBYS. These ships used the ASR1—basically an Admiralty-developed engine for submarines—but needed eight sixteen-cylinder main engines and four eight-cylinder generators. The design was not repeated as gas turbines came in vogue. Under the pressure to save weight and space in the new gas turbine ships it was decided to fit high-speed diesels as the generator prime movers. Such engines had been fitted for use in harbour or emergency in the LEANDER Class but coming to terms with total dependence on them proved a painful experience. The production of fresh water had traditionally been effected by steam-heated evaporators, and for the Types 21 and 42 Classes auxiliary boilers and steam-heated distilling plants were fitted. The maintenance load associated with that decision was far higher than forecast.

The really major changes associated with the decision to fit the Tyne and the Olympus were concerned with the control of machinery and the handling of fuel. Electronic controls for the remote and automatic control of machinery, including remote control from the bridge, led to a revolution in watchkeeping practice—and also to a major change in the skills required of the maintainers. Fuel was stored on board in a water-displaced system and the cleaning of the fuel and the separation of all traces of water led to the need for very complex fuel systems. With all these changes, total commitment to repair by replacement became inevitable. The rationalization of spare parts and the cataloguing, ordering, storing and supplying of spares worldwide became a very large operation.

The 'Invincible'

The Future Fleet studies which had been put in train following the cancellation of the aircraft carrier identified the need to deploy Sea King helicopters at sea in the anti-submarine role. For this a large (about 20 000 tonne) and fast (30 knot) ship with a long flight deck, hangars, aircraft lifts, etc. was needed—another aircraft carrier was emerging, though no one was allowed to refer to it as such. The design was at first described as the Through Deck Cruiser and sensitive eyes were normally shown pictures of the ship in profile in which the aircraft carrier resemblance was not obvious. Catapults and arresting gear were excluded, and no angled deck was provided, but as the design developed the practicalities of operating VSTOL Harrier aircraft from it became obvious, and the ski jump was added to improve the short take-off performance of these aircraft.

The design of ship which developed into the INVINCIBLE Class is of particular interest because of the breadth and thoroughness of the preliminary design studies to evaluate possible machinery fits. A very large number of variants was examined. Arrangements with two, three and four shafts were considered and steam (including nuclear powered), diesel and gas turbine machinery was evaluated—the absence of steam catapults conferred great freedom on the machinery selection. At the end of an exceptionally wide-ranging study the first recommendation was for conventional oil-fired steam machinery: the large electrical load and the requirements for heating and fresh water distillation had swayed the arguments. At this stage George Raper, who was the Director General Ships, showed his true mettle. He had started the revolution and he recognized that it might be fatal to appear to hesitate. And so gas turbines it was to be: four Olympus on two propeller shafts. The two engines on each shaft drove through a very large reverse/reduction gearbox—at 140 tonne weight, one of the largest marine gearboxes ever made.

A test facility was established at Rolls-Royce, Ansty, and a port shaft set of main machinery engines, including uptakes and downtakes, gearbox, control systems, etc. was installed and subjected to protracted testing.

Electric power in these ships was provided by eight Paxman Valenta diesel generators, and six boilers were fitted to provide steam for domestic purposes and to run the distilling plants. Although the gearboxes were very large and heavy, the machinery layout was of almost classical simplicity (FIG. 13). Machinery spaces were less cluttered than any that had been built in modern times and access to equipment for maintenance was luxurious. Special removal routes were built in to enable diesel prime movers, gas turbine gas generators

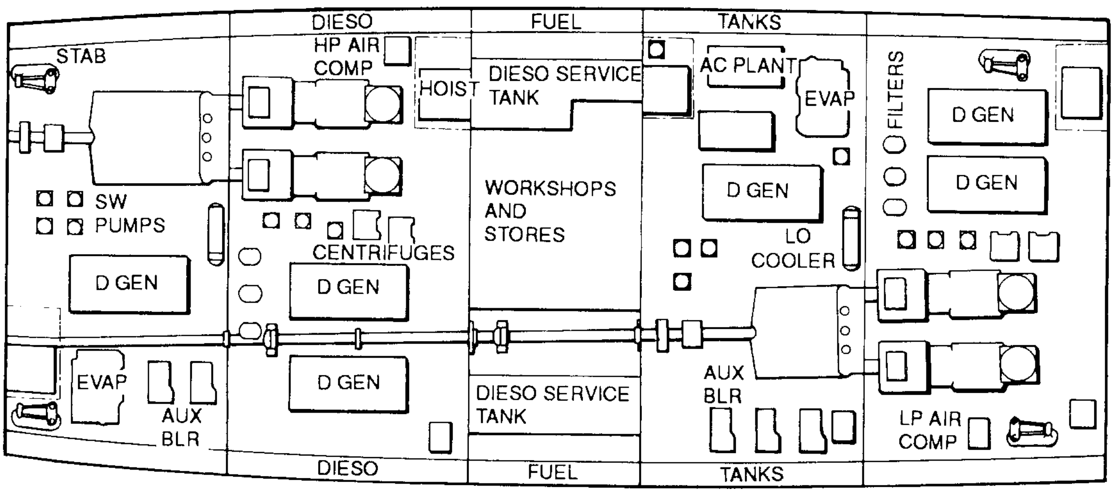


FIG. 13—HMS 'INVINCIBLE' MACHINERY ARRANGEMENT

and virtually all other major equipments to be removed for repair ashore. The flexibility of the machinery arrangement, with two identical engines on each shaft, the easy access, the absence of complex hydraulic and other systems in the bilge, have all contributed to producing very high availability in these ships.

Type 22 Batch III

The S curves for the Types 21 and 42 were similar (FIG. 14), as were those for the Type 22 (BROADSWORD) Class. This latter class, intended as the definitive replacement for the LEANDERS, was designed for the same Tyne/Olympus fit as its immediate predecessors, and the same alternators, cp propellers, boilers and distillers were fitted. For the last batch of the Type 22 the main engine fit was changed and Rolls-Royce Spey Engines replaced the Olympus. The Spey (FIG. 12) was an aircraft engine with a long and highly successful pedigree in both civil and military applications. Like the Tyne, it needed extensive modification to make it suitable for marine use and the changes meant that full development testing was required. The engine offered the promise of longer overhaul life, greatly improved economy, smaller size and good potential for future development. Nevertheless its power was less than that of the Olympus which it replaced, so it was necessary to redesign the propulsion system to enable both engines on each shaft (Tyne and Spey) to run at the same time in order to produce the required full speed. The machinery arrangement is known as Combined Gas and Gas (COGAG). The Batch III Type 22s also benefited from the introduction of new engines, Paxman Valentas, to power the alternators. The Valenta engine had originally been developed by Paxmans for use by British Rail. The exceptionally demanding rail traction cycle posed by the 125 trains sought out every weakness in the engine and much development took place. From this the Navy profited. The engines were first fitted as the alternator prime mover in the INVINCIBLE Class and they are fitted in the Type 23 as well as in the UPHOLDER Class SSK. They have also proved to be excellent propulsion engines in fast patrol boats, coastguard vessels and similar craft.

The COGOG and COGAG engine arrangements in the Types 21, 42 and 22 have justified to the hilt all the hopes of the early protagonists of gas turbines. The flexibility and reliability of the arrangement, the success of the repair by replacement policy—main engines are regularly changed in less than 36 hours—the reduction in engine room complements, and the vast improvements in working conditions in machinery spaces have transformed the role of the

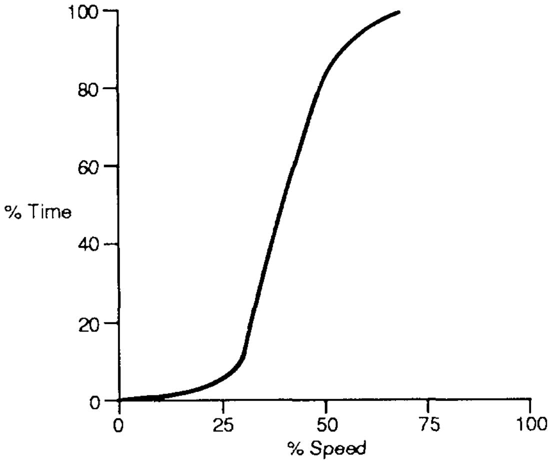


FIG. 14—SPEED/TIME DISTRIBUTION CURVE FOR TYPE 21/42

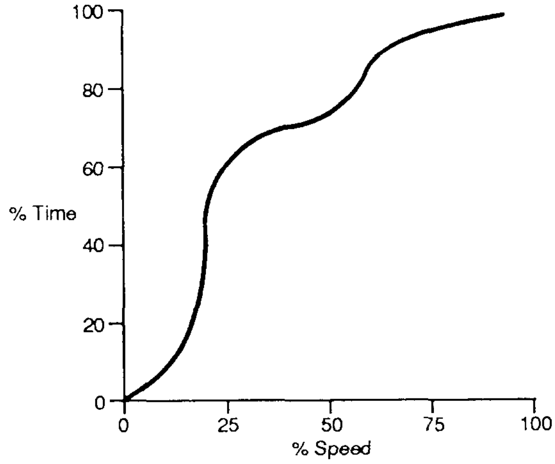


FIG. 15—SPEED/TIME DISTRIBUTION CURVE FOR TYPE 23

Marine Engineering Branch of the Royal Navy. Even so the introduction of these new engines has not been trouble-free but the problems have mainly concerned the auxiliary systems. The snake's honeymoon of the hydraulic system for the cp propellers in some of these ships meant that the lower levels of the engine room were every bit as congested as those of a LEANDER. Early maintenance problems with the boilers and steam systems (only needed to run distilling plants and provide ship's heating) threatened to discount the enormous benefits the gas turbines brought. In any future ship design the auxiliary systems will surely receive every bit as much detailed attention as the main propulsion system.

Type 23

Like almost every ship design in the history of the Navy the Type 22 had grown. More weapons were added and the ship grew in size, in capability and in cost. The Batch III ships are indeed formidable, closer in size and capability to a cruiser than a LEANDER. A cheaper ship was required to complete the LEANDER replacement programme. At the same time a new design of sonar system was evolving which required exceptional quietness at very low speed. The operating pattern appeared likely to involve a significant change in the S curve, with extended periods at very low power interspersed with bursts at high power—the so-called drift and sprint mode (FIG. 15).

The low speed noise requirements made gearing unattractive and electric drive came under consideration. At first electric drive appeared to be unacceptably expensive and demanding in space, but when it became evident that the same generators could provide both propulsion power and electrical supplies for domestic and weapon use, electric propulsion for low speeds became highly attractive. Electric power is supplied by four Paxman Valenta diesel alternator sets, the same basic engine that powered the alternators in the INVINCIBLE and Type 22 Batch III classes. Power for higher speeds is provided by one Rolls-Royce Spey driving through a double reduction gearbox on each shaft, in conjunction with the electric motors—noise is less important at sprint speeds. Astern power is achieved through the electric transmission so neither a cp propeller nor reversing gearbox is required. The ship is all electric—no boilers and no steam system, to reduce the maintenance load, and fresh water is produced by reverse osmosis plants. This machinery construction is known as Combined Diesel Electric and Gas (CODLAG) (FIG. 16).

The success of the concept has caused a searching review of development plans for marine equipments. The need for a gas turbine with high efficiency over a wide range of power becomes much less pressing if diesel engines can be used at the low power end of the range. Reversing gearboxes or cp propellers are no longer needed with electric drive. The great need, in the face of severe cuts in Navy manpower, is to save men. In terms of operation that has already been achieved by the use of modern automatic control and surveillance systems. In terms of maintenance, quality and reliability have become major design aims. The result is an engine room complement of 36 ratings compared with 48 in a Type 22 and 56 in a Type 42, and further savings can be expected in future classes.

Conclusion

It will be seen that the major influences in post-war machinery design have been the identification of the operating pattern, the quest for improved availability and the unremitting pressure to reduce the size of the crew. There is no reason to think that these major influences will change. They may be

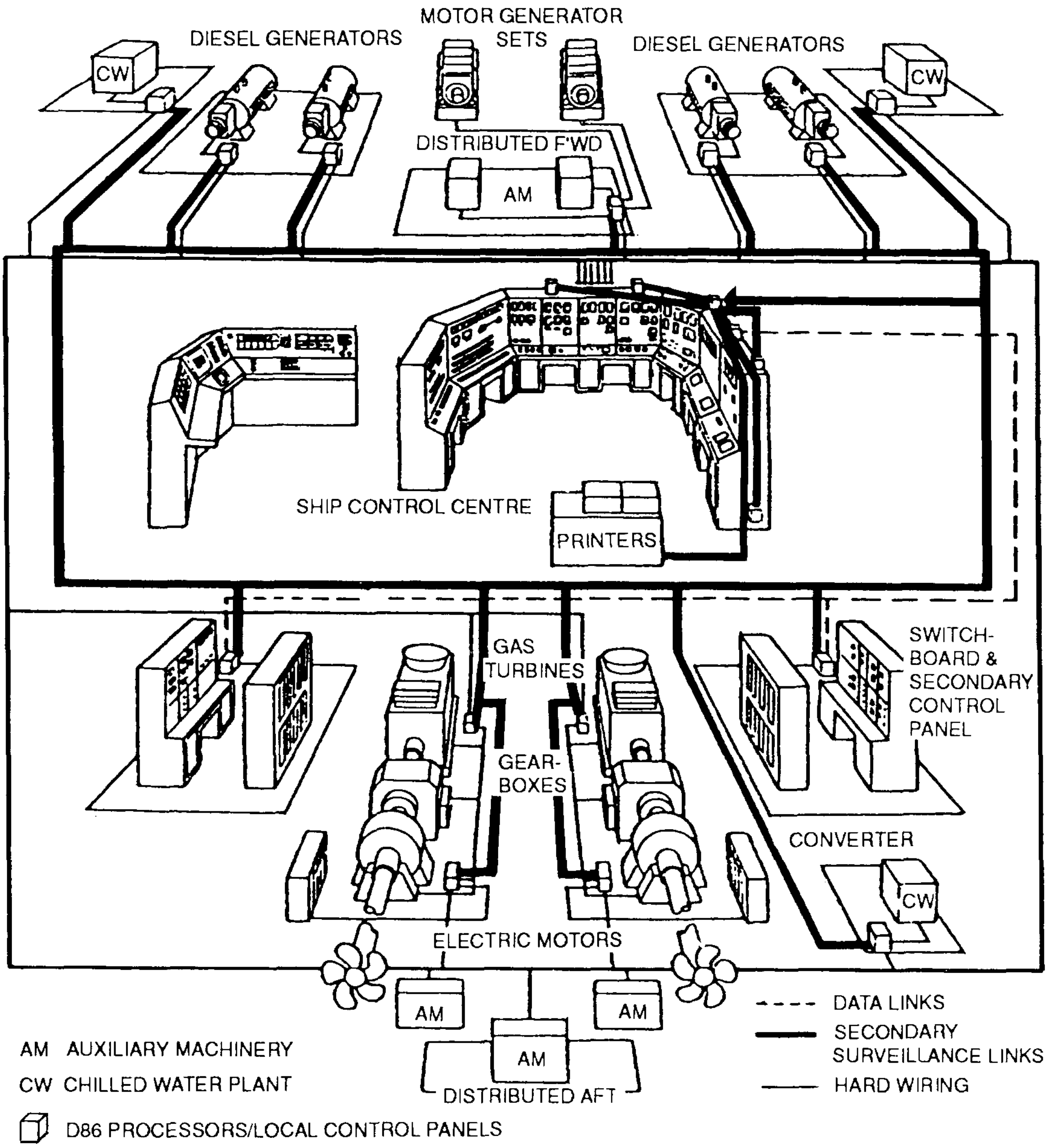


FIG. 16—TYPE 23 MACHINERY ARRANGEMENT

modified, and the requirements of stealth and survivability will certainly not diminish. A new influence may well become the power requirements of future weapon systems. If pulsed power weapons become a reality the power needs of propulsion may pall into relative insignificance.

Perhaps the days of dramatic change are now past. Steady progression, incremental change, detailed analysis and improvement in system design, continued development of equipments to increase efficiency and reliability—today these seem likely to be the themes of future papers to this Institute on naval machinery. And yet it is foolhardy to make such forecasts. Who, fifty years ago, would have foreseen the present Naval machinery fits? Does anyone believe that the next fifty years will not see at least similar change? What about the effects of exhaust emissions on the environment, or of the architecture of unconventional multihull or surface effect ships on propulsion machinery? Will the effects of stealth or survivability lead to a radical re-evaluation of the requirements for frigate propulsion plant? Will MHD become a practical means of propulsion? The possibilities are legion.

Whatever the future holds we can be sure of this: future naval machinery will demand the very highest standards of the engineers and technicians who design it, make it, install it, operate it and repair it. We can also be sure that this Institute will continue to promote these high standards and to influence the education, training, accreditation and continuing professional development of all the members of our profession.

Reference

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