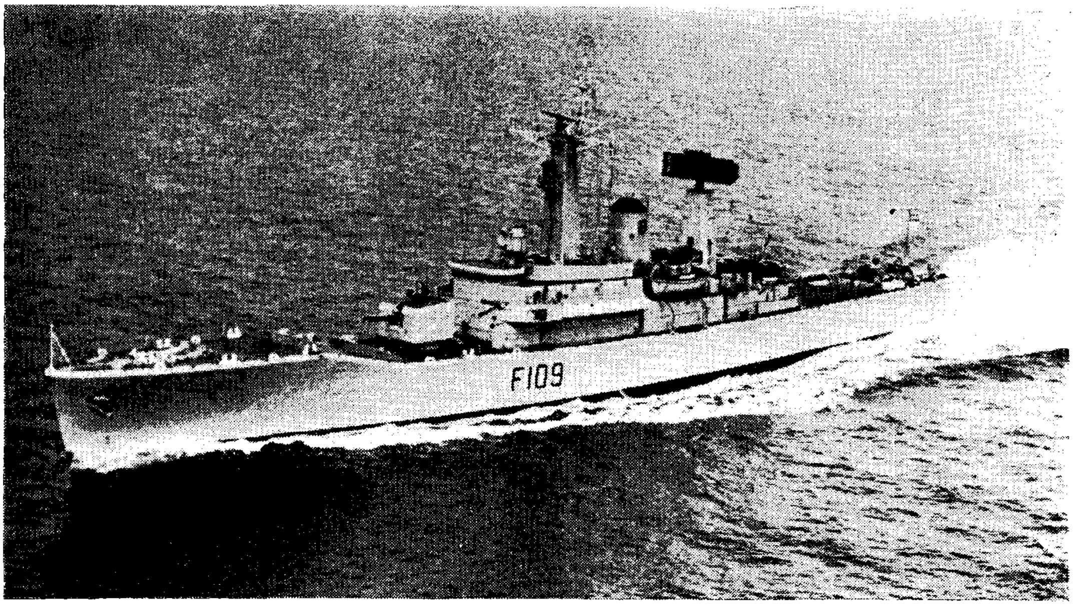

FIG. 1—H.M.S. LEANDER

POST-WAR DEVELOPMENT IN NAVAL PROPULSION

BY

VICE-ADMIRAL R. S. HAWKINS, C.B., M.I.MECH.E., M.I.MAR.E.

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INTRODUCTION

In the 21st Parsons Memorial lecture of 1956, the Engineer-in-Chief of the Fleet, Admiral Sir Frank Mason, reviewed progress in Naval Propulsion Engineering over the previous ten years. He defined that progress in three phases:

Phase I. Development based on requirements learned from World War II and using engineering achievements up to 1950.

Phase II. Development influenced by new armaments fitted in ships combined with the requirement to face attack by nuclear weapons and using engineering achievements up to 1955.

Phase III. Development influenced by the use of Atomic Energy for propulsion, using engineering achievements that could reasonably be attained by 1960.

In those ten post-war years, affected as they were by the possibility of nuclear war and the realization that atomic energy, in use for power generation, was now a possibility for propulsion purposes, we had put the Y.100 steam turbine machinery to sea in the Type 12 A/S frigates; Diesel machinery in the Type 41 and 61 A/A and A/D frigates; we were designing the gas turbine boost machinery installation for the Type 81 General Purpose frigates and the Guided Missile destroyers; and we were starting work on nuclear propulsion for submarines. It is therefore very opportune now to discuss what our new machinery has achieved in service and to reflect on our preparedness for what may be ahead.

STEAM MACHINERY

The Y.100 machinery, giving 30,000 s.h.p. on two shafts in the Type 12 A/S frigates was our first post-war attempt at a fundamental study of the design of warship propulsion machinery, using information from every source in the country. The targets set were severe, but they were achieved. We had many operating troubles, however, perhaps more than one might have expected from a new design so extensively studied. This was partly because the overall ship design was so successful that its operational role was extended far outside the original concept, and the ships were steamed at a very high rate of usage. The development of this design through several repeat classes, until we have one of the most successful ships of our time capable of still further development, taught us much about the way to success in machinery design, and it is worth discussion in more detail. One of the latest to enter service, H.M.S. *Leander*, is shown in FIG. 1.

Systems were, in general, satisfactory. The problems of steam joint and steam valve leakage, which had been our great enemy in the past, had been overcome by the detail design work which we had previously sponsored. It was the equipment, particularly auxiliary and ancillary units, which was the most susceptible to failure. The reasons were:

(*a*) Much of the machinery was liable to serious breakdown due to residual dirt in the systems; to relatively slight wear, and to lack of regular but minor attention to lubrication and adjustment. A steady improvement has been maintained with follow-on ships by detail design changes and when possible these have been applied retrospectively. They varied from major changes involving replacement of an individual unit, to very small design modifications. Such minor changes could, however, have far reaching effects by improving accessibility, which allowed more thorough routine maintenance, the earlier discovery of wear and tear, improved cleanliness, and, as a result, increased morale.

(*b*) Too much dirt found its way into systems and machinery during building and while refitting. Much has been said about dirt during manufacture and assembly of machinery. Specifications have been tightened and the problem discussed with manufacturers. Impressive improvement has been made in some areas, but this must be extended to every machine and system in the ship.

(*c*) The machinery in the ships was designed in the main for refit by replacement but adequate accessibility for essential in-place routine and breakdown maintenance has not been provided. Matters have been improved by the re-design of systems and units to increase accessibility, and particular attention has been given to simplification.

(*d*) Adequate spares had not been provided to cover on-board routine and breakdown maintenance, nor indeed enough spare units or sub-assemblies to allow refit by replacement to be carried out. Action was taken to remedy this and the system is now working well. It is relevant to comment that spare gear, correctly toleranced, has never been easy to obtain from the marine engineering industry.

(*e*) Failure due to incorrect operation occurred with increasing frequency when compared with older ships. With this new machinery it became

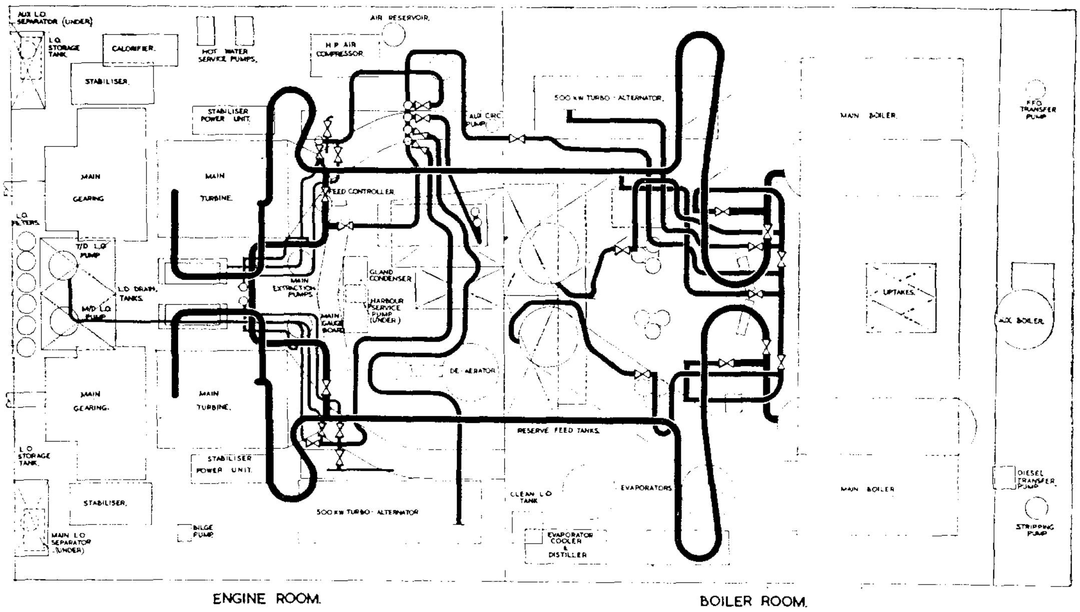

FIG. 2—LEANDER CLASS SUPERHEATED STEAM SYSTEMS BEFORE RE-DESIGN

obvious that we could not expect operators to obtain the required techniques from previous experience. H.M.S. *Sultan* has been set up as a very fine school for pre-commissioning training of engine room personnel. Its facilities include shops where machinery can be run and stripped for routine maintenance and repair. The establishment even contributes to the shore side maintenance effort required by the Fleet.

(*f*) Although operating handbooks and equipment handbooks were available to a greater extent than ever before, there was no system to ensure regular routine lubrication and adequate inspection for signs of wear and impending failure. A 'Planned Maintenance System' has now been formulated for all our new ships. Such systems are in common use by many different user agencies and much has been written and discussed about them. A few observations are nevertheless worth making. Any such system must be flexible so that feed-back from operators and maintainers reduces the planned work to a minimum. This feed-back must also reach the designer who should have been the originator of the basic plan. Attempts must also be made to provide the user with means for deciding when repairs must be done without having to resort to extensive dismantling purely as a routine. This is important because a routine must cover those ships which for some set of environmental conditions require the highest frequency of routine. Unless some easily found quantitative or qualitative parameter can be used to determine when refit is essential, unnecessary work may be done with a consequent reduction in availability. This is further discussed in the section on 'Control and Surveillance'.

It is important to note that these troubles arose despite prototype trials of the propulsion machinery on shore. These trials were invaluable in many respects and certainly could not have been omitted when introducing advanced designs of machinery. But they cannot be assumed to replace extensive investigation and development of details affecting all phases in the life of the machinery, both before the ship is commissioned and while it is in service.

Parallel with these developments to machinery installation, extensive changes in weapons and other ships' equipment were being made. These meant increased

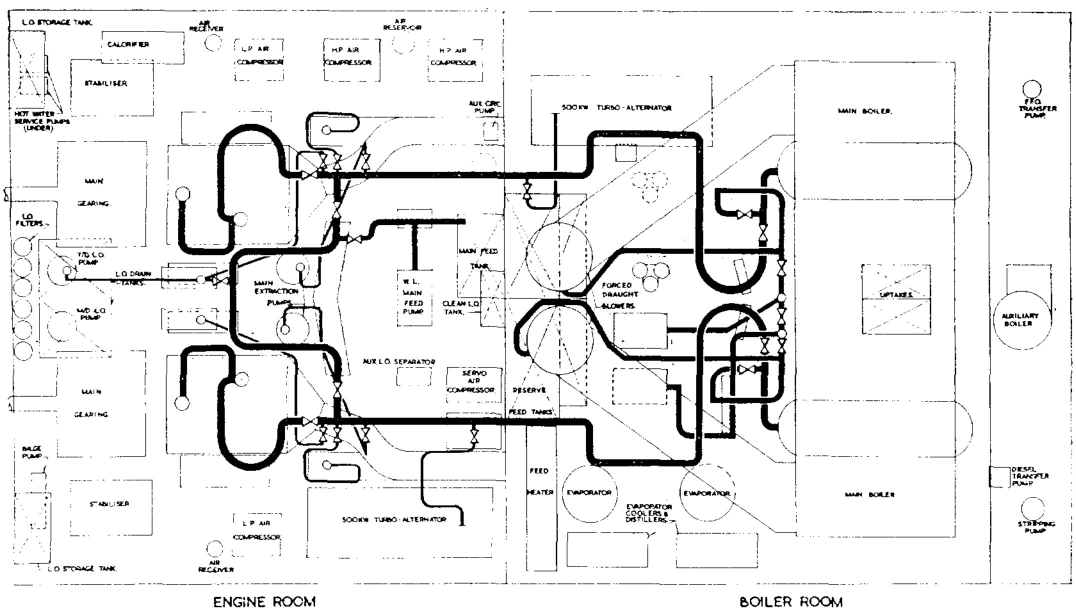

FIG. 3—LEANDER CLASS SUPERHEATED STEAM SYSTEMS AFTER RE-DESIGN

electric power supplies and extended ancillary services, but the value of the persistent development work is proved by the fact that these increases were provided at the same time as machinery accessibility was improved and maintenance reduced. The moral of this history is that progress can only be successfully made by a research and development programme which starts before design begins, and continues during building and even after commissioning. The overall excellence of the basic design of the whole ship was sufficient to ensure many repeat ship orders which allowed incorporation of modifications fed back by sea experience, which, in turn, stimulated some retrospective modification of earlier ships.

An example of the development effort put into these ships is the re-design of bilge pipework and of the steam systems. A very considerable clean-up was possible leading to much improved access, reduced maintenance, and reduction in weight and production effort. The steam system re-design involved a lot of computer work in system stressing to obtain optimum results, and some alteration to machinery layout. This work was carried out in collaboration with the Yarrow-Admiralty Research Department. The results of this work are shown in FIGS. 2 and 3. The cost was considerable but the results worth while.

The other main steam plant development project of 1956 was the Y.E.A.D.1 prototype set at Pametrada. This was not developed into a particular ship installation, but many very important concepts which were needed for our new ships in order to meet new operational requirements, were thereby proved. In particular, many new control ideas were developed and it is certain that this plant was a very necessary forerunner to the steam plants of the G.P. frigate and G.M. destroyer gas turbine boost installations.

We are now engaged on the design of the new aircraft carrier. It is yet too early to say much about it, except that it uses conventional steam machinery based on the extensive experience that we have built up with those installations already mentioned. Steam conditions are somewhat higher than are actually necessary for the propulsion plant, in order to meet the dictates of the aircraft catapults. Because of the high electrical loads, the generating plant operates at 3·3kV in order to obtain acceptable fault levels. These two features are good illustrations of how the vast amount of ancillary equipment required by modern weapons affects the overall design of the machinery plant.

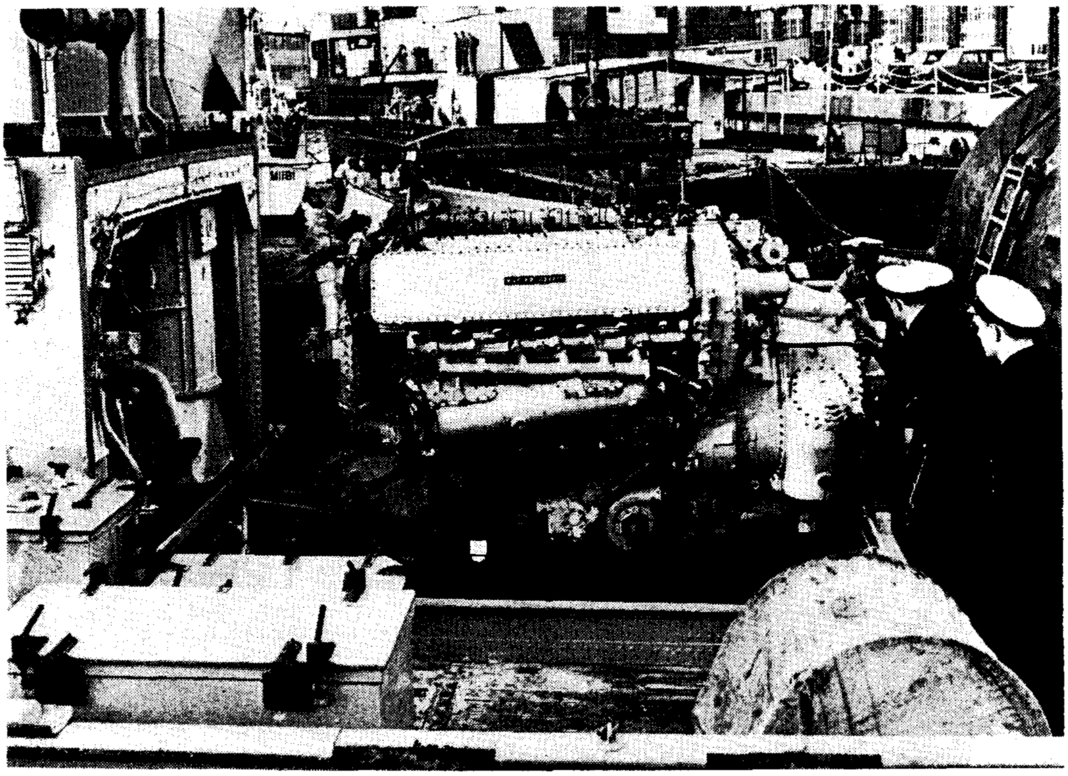

FIG. 4—REMOVAL OF A DELTIC ENGINE FROM A C.M.S.

DIESEL ENGINED WARSHIPS

The A/A and A/D frigates, using the Admiralty Standard Range I engine, were the highest powered Diesel ships that we could design in the early 1950s. These two-shaft vessels developed 8,000 b.h.p. per shaft from four Vee 16 turbo supercharged A.S.R.I. engines. Power generation was by 6 and 8-cylinder versions, thereby achieving some standardization. These vessels were the first major warships propelled by Diesel engines, except submarines, which we had designed for many years. Eight ships have been built and the oldest has seen eight years' service. This has built up considerable experience to guide our Diesel ship design philosophy for the future. These ships have achieved a good standard of reliability and are very good 'runners', but they were not without their problems in their early days. Besides a number of small modifications, two fairly major changes to the initial design were found to be necessary. The first was a weakness in the cylinder-head joints due to the inferior properties of the cast-iron liners. These were therefore changed to steel and this had the added advantage that engine damage was minimized in the event of a serious failure in one line. The second trouble was undue wear and consequent backlash in the camshaft drive gear train which was remedied by changing from soft to hardened and ground gears. The design troubles could not be considered unreasonable for a completely new engine and installations, but our major problems were production ones associated with the development of a completely new machinery installation. These were overcome eventually and we have learnt a great deal concerning standards of design, tolerance and inspection procedures in the process.

Sufficient running experience and development has now been accumulated to permit a 50 per cent increase in the planned major overhaul interval, and this is very welcome in a ship with so many propulsion engines. This prompts me to make some observations on the design philosophy of Diesel-engined ships and how recent developments are leading to new ship design concepts. Although, as I have already stated, the A/A and A/D frigates have proved themselves to

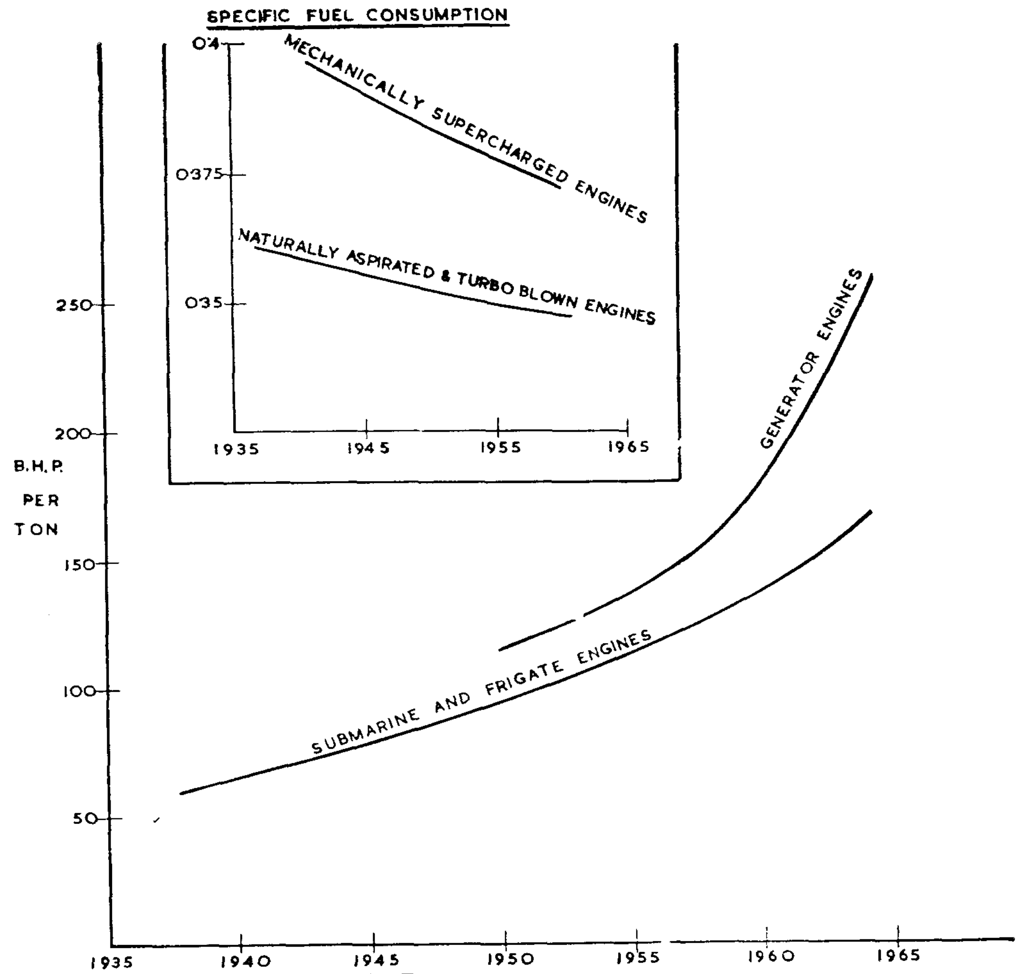

FIG. 5—DIESEL ENGINE DEVELOPMENT

be reliable, flexible and economical, multiplicity of propulsion engines leads to a large maintenance load, particularly in dockyards during ship refits. At the time the engines were designed, however, this was unavoidable, because our limited knowledge forced us to use comparatively high-speed engines of low power in order to achieve the modest specific weight target of 18-20 lb per b.h.p. necessary in this ship design. If it were possible to reduce to two engines per shaft a better compromise between operational flexibility and maintenance effort would be obtained with reduction in costs. Recent advances in Diesel engine design are now bringing within reach installations of a better overall balance. With the prospect of medium-speed engines of very much higher power with low specific weight there is a good case to be made for the use of the propulsion Diesel engine in naval ships. These advances are being made by the careful optimization of all design and turbo-supercharging parameters, and in frame design which has for so long been a barrier to the achievement of high specific outputs.

There has also been a big advance in the design of slow running, direct drive, propulsion Diesel engines. They cannot yet be used in warships where the demand for weight and space is so great, but they will find greater use in some Fleet Support ships which are suited to that type of engine.

The remarkable Deltic engine which was designed at the same time as the A.S.R.I has continued to prove its excellence. Its very fine power/weight ratio of 4½ lb per b.h.p. gives it, of course, its specialized role, for without it the ships in which it is used could not have been designed. There is also another advantage in that the engine can be changed in a matter of hours, which does much to improve ship availability. This operation in a coastal minesweeper is shown in FIG. 4.

To sum up the story of Diesel engine development, the trend in design is illustrated in FIG. 5. This advance in performance, coupled with extension of overhaul intervals and reduction in maintenance requirements, which are the results of both improved design philosophy of engine and installation as well as extensive component development, foretells a healthy future for Diesel engines.

COMPOUND PLANTS—WITH PARTICULAR REFERENCE TO THE GAS TURBINE

Combined steam and gas turbine plants are now at sea in the *Ashanti* Class frigates and the *Devonshire* Class destroyers. The original concept was a combination of steam turbine and gas turbines such that normal steaming and manoeuvring would be executed with the steam installation, the light-weight gas turbines being clutched in on the comparatively rare occasions when high speeds were required. Such an arrangement saved weight and allowed a reduction in engine room deckhead height. However, with an alternative power unit available and the thought that nuclear war would demand that ships be able to leave harbour at very short notice, the concept soon developed into that of a dual plant which allowed manoeuvring and steaming for considerable periods on gas turbines alone. This meant that the immediate post-war design approach explained by Admiral Mason, which tended towards the development for this project of a light-weight aircraft engine, became remoulded because it was thought that the requirements then demanded could not be met by available aircraft engines. These requirements were:

(*a*) Complete gas tightness of engine casings

(*b*) Ability to withstand shock

(*c*) Ability to operate when submerged

(*d*) The provision of white-metal bearings in place of ball and roller bearings and, to a lesser extent, the apparent lack of interchangeability of components.

These changes led to the development of the G.6 engine which is a medium weight marine gas turbine. This effort was supported by a prototype shore plant consisting of two gas turbines, a reverse reduction gearbox and suitable clutches. Such a shore plant was essential before the gas turbine propulsion system could be sent to sea. The fact that a brand new gas turbine was being designed and developed at the same time as the building and installation of production engines made it very difficult to incorporate the many inevitable modifications. The cost of the prototype shore plant was a little over £2m, which is small by comparison to Ministry of Aviation costs for aircraft development work. However, a shore plant alone was not entirely adequate for what proved to be a difficult and complicated development programme. Much more extensive, and therefore costly development is required before a new design of gas turbine is put into service.

Some of the difficulties met during development work were:

(*a*) Full power was not reached until the G.6/2 design had been developed. This loss in power was due to distortion coupled with problems of cooling air distribution.

(*b*) A serious failure in H.M.S. *Ashanti* was partly attributable to the inadequate supply of cooling air which only became critical under tropical conditions. The subsequent investigation and the re-design of cooling air flows improved running conditions and raised engine performance.

(*c*) Some compressor fixed blade cracking developed due to vibration, combustion chamber cracking and distortion, and combustion troubles.

FIG. 6—H.M.S. KENT ON ARCTIC TRIALS

(*d*) Rotating stall in the compressor at one speed which imposed a restricted running range.

These troubles were overcome by continued use of the prototype rig and by the use of a test gas turbine at the Naval Marine Wing of the National Gas Turbine Establishment. This gas turbine is installed with extensive research instrumentation.

The other use of gas turbines for warship propulsion has been in the *Brave* Class fast patrol boats. These craft use the marinised *Proteus* engine and are thus an application of the original aircraft gas turbine policy. These engines had some minor faults which were cured and experience has been one of growing dependability and increasing life. The outstanding problem was that of deterioration of performance due to fouling of compressor and turbine blades which initially meant that the engine had to be removed for stripping and cleaning at relatively frequent intervals. However, with improved cleaning methods, the period between stripping has been doubled. A better appreciation of the effect of the difficult marine environmental conditions on an aircraft gas turbine was also obtained.

As a result of this invaluable experience, a re-assessment of certain marinised aircraft engines has been made to allow reconsideration of design policies. It is apparent that during the last few years aircraft engines, with their background of large research and development expenditure before being put into service, their first class manufacturing control and a high usage and proving rate in the air, have shown large increases in flying time between overhauls. Together with their very good specific weight, specific fuel consumption and improved methods of engine mounting, these have led to revised thinking on the use of actual, but marinised, aircraft engines in any warship whose design might benefit by their use. The basic thought still remains firmly established: to use simple cycle engines. The simple cycle aircraft engine has a good specific fuel consumption even at part load. When used at derated powers suitable for ship use, a good engine life should be obtained while still achieving a comparatively low specific weight by ship standards. Whatever the reasons for and against the use of gas turbines in a particular ship, one aspect which must always be clearly and carefully defined is their suitability for service in marine environments: a problem which has always been a severe one for ship-borne machinery.

The steam machinery of the COSAG plants also had teething troubles. In general, the main propulsion and ancillary machinery worked well from the start. Most defects occurred in propulsion auxiliaries and their associated systems, where a succession of design faults, often minor in themselves, led to loss of availability and a hectic settling down period. One particular problem was extensive failure of the smaller heat exchangers, usually due to design shortcomings associated with the integration of the coolers into the circulating water system. Naval experience over the last ten years has clearly shown that most of the teething troubles in the first ships of a new class occur in the auxiliary machinery. In many cases these are not due to faults in the design of particular machines, but because of failure to integrate correctly the individual auxiliaries into the installation as a whole.

Other types of combined plant can be envisaged, in fact, any combination of different prime movers is possible, but before their use can be considered, the correct reasons must be established. There is no place in an engineer's philosophy for the use of two different types of plant merely for the reason that one plant may be a workable proposition if one has made a mistake about the other. This is not to say that a correctly balanced system of stand-by equipment should not be provided, although if reliability can be more confidently guaranteed than is usually the case today there is good reason to reduce stand-by arrangements, so long as the overall design philosophy allows the right degree of recovery from the maximum credible accident. One type of combined plant which is much discussed is the Diesel and Gas Turbine (CODAG) Plant. The advantage of this type is a considerable saving in machinery plus fuel weight for a plant which gives high endurance at low speed, but yet has a high-speed capability, at a probable cost of a comparatively low endurance and short engine life. If such a ship is required, then the CODAG plant is attractive. The important point to remember is that the choice of machinery must be made in the context of the required capability of the ship as a whole, after the proper balance between the conflicting demands of weight, space, speed, endurance, maintenance, noise, vulnerability, cost, weapons and manning has been established.

NUCLEAR PROPULSION

The Naval Staff have kept a close watch on nuclear propulsion development from the earliest occasion that it was accepted that power production was possible by this means, and naval representatives have been stationed at the Atomic Energy Research Establishment, Harwell. In 1954 it was decided to proceed with the design and construction of a nuclear plant suitable for a submarine, and representation at Harwell was accordingly supplemented with personnel from industry to work in conjunction with U.K.A.E.A. technicians. Extensive studies were undertaken of various systems, from which emerged a number of attractive features. Support facilities in the form of research reactors, *Lido* for shielding studies, and *Neptune* for core and control performance studies, were provided. Heat transfer and corrosion experiments were conducted in both 'out of pile' and 'in pile' loops installed at the Atomic Energy Research Establishment and contractors' works. As a result of this work a beginning was made with the construction ashore of a prototype submarine machinery plant at Dounreay.

In 1958 the Mutual Defence Agreement enabled us to purchase a complete submarine propulsion plant from the United States and also to make arrangements whereby a limited amount of design information was obtained for manufacture of plant in this country. This culminated in the construction of H.M.S. *Dreadnought*, now operational, and had a major influence on the Dounreay submarine prototype design. Two submarines of the *Valiant* Class, and four *Polaris*-type submarines are now on order.

FIG. 7—JASON REACTOR

As in all such projects, a vast support structure was required to give training facilities, operational bases, refitting and refuelling bases and safety surveillance organizations. Extensive courses of instruction have been instituted at the R.N. College, Greenwich, where a *Jason* reactor is installed, at H.M.S. *Sultan*, and at the Dounreay Reactor Test Establishment.

Although there has been much American help in this work, one must not underestimate the 'know-how' achieved by British industry by virtue of the initial British work, particularly in the field of pumps, valves, and the fabrication of systems under the very clean conditions required for such plants. Nuclear engineering has not been with us for very long, and in pursuit of better materials and technologies extensive programmes of research and development are being executed by the Navy Department and by industry. Also under continuous study is the application of nuclear power for surface warships and a close watch is being kept for potentially suitable designs.

CONTROL AND SURVEILLANCE OF MACHINERY

Local, self-acting controls such as governors, reducing valves and steering mechanisms have been a part of naval marine engineering life for a long time, while the first use of an externally powered system in the control of closed exhaust back pressure, was introduced many years ago. It is, however, in the last five years that the major impact of modern control techniques on naval machinery has occurred. The subject has been dealt with in detail in a recent paper to the Scottish Section of the Institute of Marine Engineers* and further discussion is hardly necessary in this lecture. However, the philosophy behind

* *Journal of Naval Engineering*. Vol. 15, No. 1, p. 122.

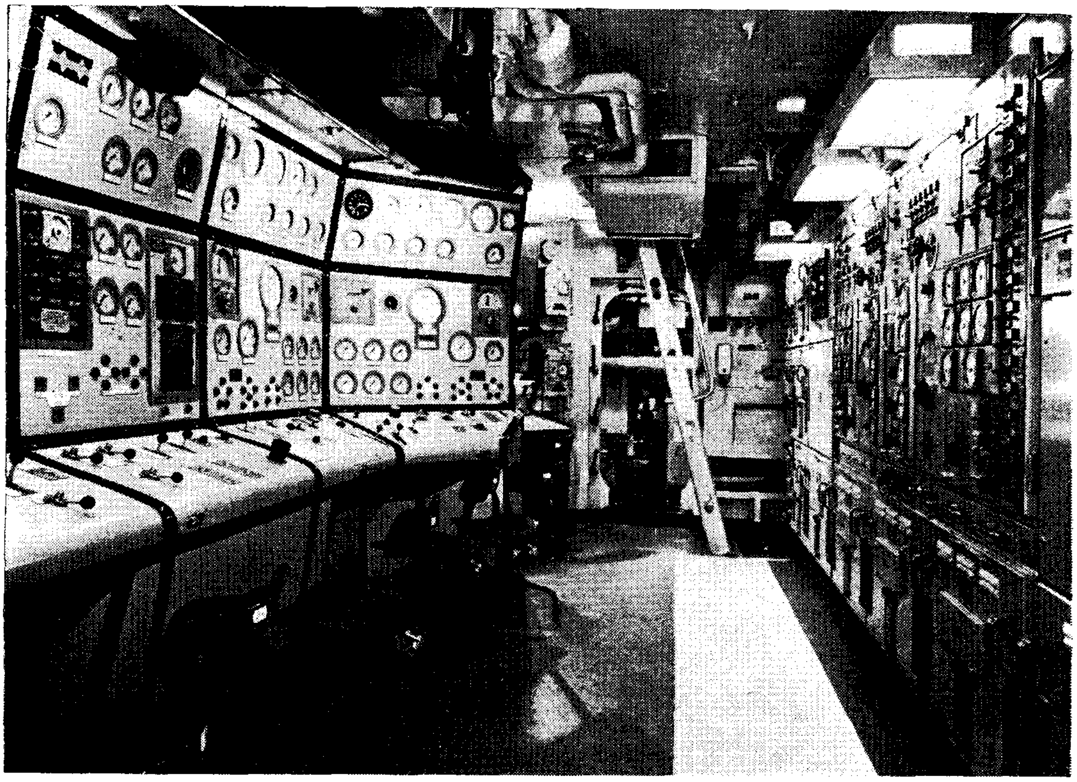

FIG. 8—MACHINERY CONTROL ROOM—H.M.S. HAMPSHIRE

the wider use of control systems in naval propulsion machinery is worth explaining as the reasons for their use are often misunderstood.

Their widespread introduction came about entirely as a result of a Staff Requirement calling for protection of machinery watchkeepers in modern warfare while retaining complete power of manoeuvre. The result was tantamount to a re-drawing of the division of labour between men and mechanism. In the first place a somewhat arbitrary decision was made to introduce remote control of the installation, backed by automatic controls. The basic principles can be briefly described as the use of remote control to vary shaft power output while automatic controls adjust individual units to allow manoeuvre over the whole power range. Fortunately this arbitrary division has turned out to be close to the optimum for naval purposes. It was only after the equipment came into service that other advantages, other than that of personnel protection, became apparent, and these are discussed later.

Much progress has been made in the last few years and the point has now been reached where remote operation by control systems has almost reached the profitable limit, though not yet in the most effective or simple manner. The control systems used by the Navy are linear systems, which allows the use of simple design techniques. This type of system is, however, unnatural to machinery and calls for complication in the actual machinery installations, which are generally non-linear, in order to match the equipment to the controls. It also sacrifices some fuel economy. Future thoughts are therefore on non-linear lines in order to eliminate these complications at the cost of more complex design thinking. Mechanization of the watchkeeper's function of manual machinery operation which is all that our remote and automatic systems do, does not, however, cope with the higher intellectual activities associated with machinery surveillance. There is much to do in devising equipments and information systems to match the ingenuity of the control systems.

Surveillance of running machinery installations can be split into many levels of intellectual activity covering the whole range of machinery management, dealing with its operation, maintenance and refit. This involves not only the accurate and timely production of a large amount of data, but also the capacity to reduce it to a usable form for all levels of control and management.

It is therefore with the achievement of compatability between the control systems and the surveillance systems that one is extensively concerned, and the broad approach to the naval problem is:

(*a*) To re-draw the division of work between humans and mechanisms so as to exploit the capabilities of both to the optimum amount, i.e. to do the total job of operation, maintenance and refit, better.

(*b*) To accept that effective design of machinery and control systems will not be obtained by regarding as paramount the reduction of engineering complement.

(*c*) To accept that engineering complements cannot be reduced below some undefined level sufficient to cope with machinery failure, action damage and other military requirements.

(*d*) To accept that the presence of manpower, in excess of watchkeeping and other normal requirements, should not inhibit the mechanization of work where this is profitable.

These principles may appear to contradict the widespread belief that the use of control and data-processing techniques is entirely aimed at the reduction of the shipborne staff at present required for a non-automated ship. There is no doubt that a reduction in the manpower that is required to run a ship is of extreme importance, but it is essential that the development of control systems in naval ships is not pursued along the one track of trying to reduce ships' staffs. The need is to design the whole installation to do the total job better: operation, maintenance and refit. Exactly how one defines this is open to discussion, but for naval ships a suitable one would perhaps be the availability/cost ratio for a given usage rate. Experience is beginning to show that by aiming for this larger target one is likely to reduce on-board staff even more, for only then is full scope given to simplification of the whole installation as much as economics allow. A conscious effort to simplify the installation as a whole is the most important state of mind for any designer when so much is demanded from modern systems. This requires much sophisticated design thinking.

Although the Merchant Ship installation is not usually called upon to perform such a variety of functions as a naval one, and the economic pressure to reduce shipborne complements is even greater, the same philosophy is a sound one to cultivate.

Besides a reduction in watchkeepers, naval experience in about twenty ships fitted with full remote control has confirmed the fact of other important advantages. These are associated more with the automatic controls than just the remote controls. These by-products of the attempt to meet the somewhat awkward Staff Requirement for the protection of personnel are:

(*a*) High accuracy of control

(*b*) Fast response to changes in demand

(*c*) Less deposit in heat exchangers

(*d*) A reduction in pump wear and tear

(*e*) Reduction in fatigue of watchkeepers.

It is hoped that development of the machinery information systems will allow much better management of the whole process of machinery operation and control of maintenance and repair, both on board and by refitting authorities.

The research work associated with the extensive use of control systems in all our modern ships has some interesting facets which could lead to many

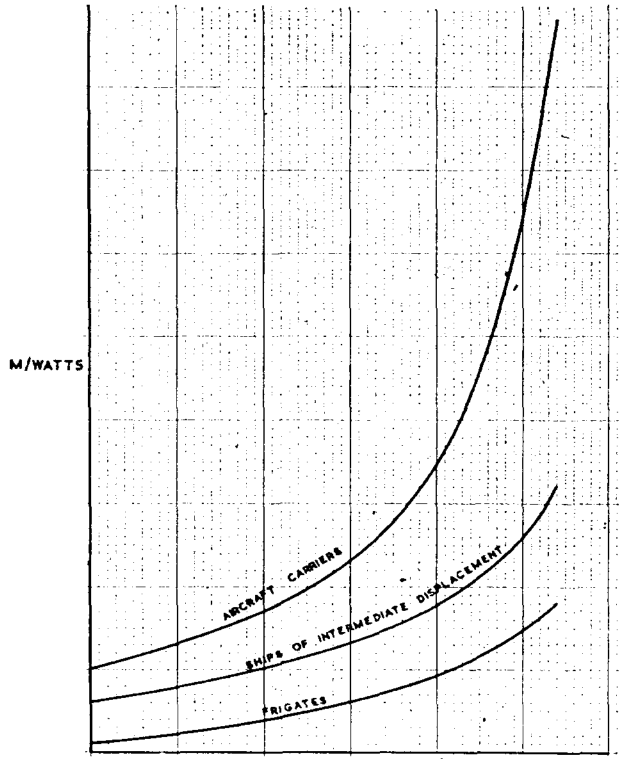

FIG. 9—GROWTH RATE OF INSTALLED ELECTRIC POWER

developments of a more general nature. The examination of the dynamics of a steam propulsion plant is being carried out by attempting the complete simulation of the machinery and hull dynamics on an analogue computer. This should yield generalized information on programmes of manoeuvre for maximum ship acceleration and a basis for developing a method of obtaining dynamic matching of machinery units in the design stage, which was mentioned earlier. It could also lead togreater simpliffcation of the steam installation

There is also the wider prospect of intregating the machinery control with the remainder of the ship and weapon systems should this be required. This could only be accepted if the integrity of the propulsion control system were not prejudiced.

THE PRESENT DESIGN PROBLEM

The world-wide commitments of the Royal Navy take many forms. Operational requirements and help to civil authorities, showing the flag, tactical exercises, surveying, fishery protection, have all to be met. This versatility and resulting high usage of our ships under varying conditions will continue for as far as we can foresee. It is important that machinery installation designs should enable ships to keep the seas for long periods with the minimum of base support. Of all the conflicting requirements that must be satisfied, most important is the need for reliability and durability. Neither of these is made easier to achieve by the ever increasing effect which modern weapons have on the design of machinery. The variety of the ancillary equipment and services, control systems and electronic gear that they require, coupled with the improved environmental conditions which must be provided for the crew in a world-wide variety of operational conditions, further aggravate design difficulties. The scope of the problem is illustrated by the almost explosive increase in installed electrical generating capacity of our ships during recent years. This is shown in FIG. 9 for several classes of ship. It is interesting to speculate on the shape for this curve in the future. Some contend, almost in despair, that it must continue upwards, others that it must turn over and steady out. The latter claim that this would be achieved by transistorization, the former claim that transistorization gives miniaturization which allows more capability to be built into a given volume, and power requirements still increase. This type of problem appears to be a worry in every walk of life for one continually sees curves of this shape. They are often referred to as if they obey either a natural law or the whims of nature, even to the extent of implying that they possess a mystical will of their own. It is forgotten that these curves are merely a way of recording our past actions and that therefore their shape in the future can be determined by ourselves. This problem has arisen because science and technology allows us to to do so many different things, each nevertheless requiring such skill and effort to put into effect, that we tend to string a succession of them together in one complicated group. Admiral Mason, however, stated that the selection of a judicious compromise of a large number of requirements is the artistry of design. Inherent in this concept is the corollary that the artistry of design is expressed by achieving a large number of capabilities with the simplest of designs. The need for simplicity is urgent today. Simplicity not only in the components themselves, but also in grouping together the minimum number of components to achieve all the design requirements and without sacrificing too much efficiency. This is the essence of good design without which uncontrolled increase will continue. Research and development expenditure must therefore increase to match the extent of the capabilities with which the plant is to be invested. This expenditure will deal with the more scientific aspects of engineering such as the improvement of blade path efficiencies, the reduction of flow losses and material research. It will also cover the art of component design, and perhaps more important than all of these, the art of installation design, to achieve the best and simplest total plant, followed by development running and endurance testing of components and installations to an extent dependent on the novelty of the design. In many cases this must continue even after the first production plants have been put to sea.

DEVELOPMENT FOR THE ROYAL NAVY

For the Royal Navy research and development work is effected by a combination of the engineer officers of the Royal Navy, the Royal Naval Scientific Service, the Royal Naval Engineering Service now being formed, and of Industry with its own backing of research and development facilities. There are many naval establishments already well known to Industry. The Admiralty Fuel Experimental Station, the Admiralty Engineering Laboratory, the Admiralty Oil Laboratory, the Admiralty Distilling Experimental Station, the Admiralty Fire Test Ground and the Naval Wings at the National Gas Turbine Establishment at Pyestock and the Royal Aircraft Establishment, Bedford, where aircraft catapults and arresting gears are developed. Since 1956 we have closed the Naval Section at the Atomic Energy Research Establishment, Harwell, and set up the Admiralty Reactor Test Establishment at Dounreay. These establishments, while carrying out the design of some special purpose equipments, are primarily concerned with testing and with research work associated with testing. In some cases, one in particular being noise problems, this involves fundamental work as well as applied research. On complete installation design work we have the Yarrow-Admiralty Research Department which works in very close association with the Director of Marine Engineering in the Navy Department. Ten to fifteen years ago the majority of our naval engineering equipment, although designed by Industry, was particular to the Navy and not apparently applicable to commercial use. However, the pressures exerted by commercial customers are now much more akin to those of the Royal Navy for a variety of rather involved reasons. This has meant that the Royal Navy can now use much more equipment that has been expressly designed for a commercial market, with perhaps some small modification to cover military requirements. Over the years, the Navy has been assembling books of requirements and specifications in an effort to obtain better equipments upon which our ships can depend in war and in the continuous cold war situations which are hardly less arduous. Most of us have seen this mass of paper and probably scoffed at it. But now that more commercial equipments are suitable in their design concepts we naturally look around for what might be called 'best commercial standards'. We have, of course, the very important Lloyd's standards which deal primarily with safety at sea. There are many British Standards also dealing mostly with safety and pure standardization for detail parts. There are, however, very few commercial standards of a wider nature concerned with the excellence of design, development, manufacture and assembly into an installation, except those inherent in the reputation of a company. Perhaps this is the right and proper arrangement in our way of life, but it is worth some thought by Industry, for it is still widely maintained by the user that too much reliance for the continuing and satisfactory operation of machinery is placed on the hard-pressed operator. It also explains why the Navy has to set up what are virtually its own 'Which' or 'Good Housekeeping Award' establishments, and has to produce such lengthy specifications to assist the contestants to pass with flying colours. It is relevant at this point to mention that we are extending the facilities at the Admiralty Fuel Experimental Station to allow endurance running of auxiliary machinery to prove designs and to help in their development before they are committed to sea service. Where necessary, this will continue after they have been put to sea, so as to anticipate any possible long-term trouble or to help solve some problem arising at sea. This arrangement will be similar to the type testing of Diesel engines at the Admiralty Engineering Laboratory. This co-operation between Industry and the Navy has helped to make the great improvements in Diesel engines over the past few years, and we hope industry will co-operate just as much in our new venture.

FINALE

This paper details the many problems that have had to be faced and overcome in developing machinery to match the exacting requirements of the Royal Navy. Much has been achieved since the war but this is a continuing process. As every engineer knows, his profession is one of steady application of hard and painstaking work with seldom any short-cut. One often hears a demand for a quick break-through which will solve either a country's problem or someone's own personal problem. Such an attitude arises from popular science programmes and publishings which glamourize and foreshorten some particular scientific line of research until it appears that the unlocking of a secret, or the achievement of some ambition is the result of the fertile brain of some particular genius. Most engineers realize very quickly that progress is the result of hard work which involves research and development expenditure before the beginning of a project, in its early stages and continuing through until well after its commissioning. The technical task which lies ahead of us in the Navy is still, and always will be, a most exacting one, but our experience in the development of machinery in the last decade should stand us in good stead in meeting the demands of the future.