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FUTURE DEVELOPMENTS IN MACHINERY INSTALLATIONS

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The paper begins by reviewing the projected growth in world tonnage up to 1985 identifying both the general trend and the ship types which are emerging. Changes in emphasis in machinery installation design are considered together with the machinery installations appropriate to large energy carriers. Future developments in machinery are discussed and related to the current and future share of the market for each type of prime mover. A gas turbine arrangement for a VLCC is presented with an economic analysis to compare the gas turbine with conventional propulsion systems and consider the impact of further changes in the cost of fuel.

WORLD FLEET GROWTH AND MACHINERY TYPES

World Fleet and Ship Types

This section discusses the projected expansion of the world fleet over the next ten years in an attempt to identify ship types which will represent a large proportion of future tonnage. The factors which affect this growth and the difficulties of making such predictions are briefly considered to provide a framework within which future developments in machinery installations can be discussed.

In 1970 the total world fleet was 336 million tonnes deadweight and it is anticipated that this will increase to about 690 million tonnes deadweight by 1980 and about 970 million tonnes deadweight by 1985 (Table I). The figures up to 1980 are taken from Maritime Transport Research Publications(1) and extrapolated to 1985 with modified growth rates.

TABLE I—SUMMARY OF WORLD FLEET DEMAND TO 1985
MILLION TONNES DEADWEIGHT

Ship Type		1970	1975	1980	1985
Oil tanker	1)	145·8	225·5	349·2	488·7
Liquid gas carriers	2)	1·1	2·8	7·6	13·6
Bulk carriers	3)	73·0	117·2	188·0	301·7
Dry cargo		97·8	98·7	100·2	100·9
Container		0·5	6·6	13·3	21·4
Non cargo & misc.	4)	17·9	24·0	32·1	42·9
World fleet		336	475	690	969

1) Active oil tanker fleet.
2) Liquid gas fleet in million tonnes.
3) Bulk carrier fleet includes combined carriers.
4) Non cargo carrying fleet in million grt included in total without adjustment.

These publications were prepared before the oil crisis of October–December 1973 and its consequences effectively suspended all previous ship demand forecasts. Revised forecasts will not be available until the long-term effects of the crisis begin to become evident and the tables and figures quoted in the paper have not been modified as they can still be used to give an overall picture. Where the change could be significant, as in the tanker market, a revised forecast is included in the text.

Table I is not regarded as a firm market prediction but it does provide a basis for considering possible machinery developments over a decade. When forecasting future tonnage requirements it is clearly important to identify the factors which influence trading patterns and the types of vessel needed to meet this demand. Generally such forecasts are based on historic information which is then projected forward without sufficient consideration of the factors influencing future development. Ideally the first step would be to establish, from projected trading patterns, the commodities to be moved, the trade routes involved and the volume. Consideration of the most efficient method of providing this service taking into account the various alternative solutions would give projected tonnage requirements. The results of this analysis would then be compared with past trends to see if the assumptions were consistent with past experience in terms of both the possible solutions and the anticipated volume. A major factor ignored in many investigations was the economy of scale which led to a complete underestimate of the sizes of tankers and bulk carriers. In the case of bulk carriers the error was magnified by an underestimate of the development in world trade of such commodities and more particularly the distances over which they had to be transported to meet changes in trading patterns.

A given volume of growth rate in trade does not automatically equate to a particular growth rate in shipping. Trading patterns and political factors have a considerable influence and the progressive elimination of trade barriers has been an important factor in the increase in shipping activity during the past 20 years. The effect of trading patterns can be illustrated by considering the cargo carried per annum divided by tonnes deadweight for various classes of ship, a ratio which changed very little between 1955 and 1970. The transportation efficiency of ships had, however, improved considerably during this period by using progressively higher speeds, obtaining a greater availability and reducing time spent in port. The tonne miles in the period 1960–1970 increased by 125 per cent as against an increase of only 85 per cent in the deadweight tonnage of shipping available.

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One of the most important factors affecting trade patterns has been the development of Asia as an increasingly important area, particularly for bulk commodities, so that Japan alone is responsible for 40 per cent of all dry bulk imports and in addition almost a quarter of the current transport of crude oil. A rapid growth in the gross national product has been made possible by the supply of raw materials or energy requirements from abroad which in turn has led to an increasing volume of finished products. A more recent feature results from an estimate that the U.S.A. will have an oil consumption of 1195 million tonnes per annum by the early 1980's. Current trends suggest that up to 40 per cent of this requirement may be imported and that by 1985 this figure may have risen to 60 per cent of the total oil supply of which 40 per cent could come from Middle East sources. The Administration has asked Congress to pass legislation permitting construction of supertanker ports, so that not all the cargoes will need to be trans-shipped from terminals in smaller feeder ships. As there is also a shortage of domestic refinery capacity, some of the processing might be done in other countries, leading to a new design of large tanker capable of carrying a limited variety of products. Fig. 1 shows the fleet tonnage demand up to 1985, previously summarized in Table I, for tankers, bulk carriers and other vessels, together with actual returns for recent years.

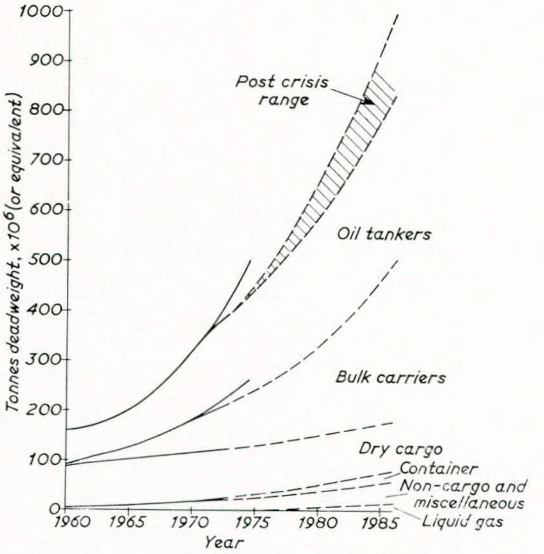

FIG. 1—*World fleet total demand*

In 1970 about 1300 million tonnes of oil and about 1100 million tonnes of dry cargo were transported during the year, with just under half the dry cargo requirement consisting of bulk commodities. From the predictions available, it appears that by 1980 about 2500 million tonnes of oil will be required, so that the tanker tonnage will have to increase from a figure of 146 million tonnes deadweight in 1970 to about 350 million tonnes deadweight in 1980, rising to about 490 million tonnes deadweight by 1985. This allows for a slight improvement in efficiency, both in terms of a marginally higher speed together with a greater availability.

The 1973 oil crisis and the new price levels have led to a revision of tanker demand and a recent interim forecast(2) suggests that the 1980 tanker demand could be somewhere within the 250–330 million tonne deadweight range depending on the assumptions made and the success of the world energy economy drives.

The expansion in world bulk tonnage including OBO and ore/oil carriers during the 1960's was very rapid, rising from 10·3 million tonnes deadweight at mid-1961 to 73 million tonnes deadweight at mid-1970. It is anticipated that this will rise to about 188 million tonnes deadweight by 1980 and reach about 300 million tonnes deadweight by 1985.

The forecast for bulk carriers has not been directly affected by the energy crisis except for the combined carriers which are included in this category. For this reason, a slight reduction would be expected in the forecast tonnages.

As it is expected that the tanker and bulk carrier categories will represent about 80 per cent of the world tonnage by 1980, they will clearly have a significant impact on the market available to the various competing machinery types. The remaining categories should not, however, be disregarded because they are generally tonnage with a high value for each gross registered ton and significant in terms of power requirements.

An analysis of tanker tonnage on order at the end of 1972 shows that there are four distinct size ranges; the first and largest being those over 200 000 tonnes deadweight which are expected to be over 70 per cent of the world tanker tonnage by 1980. An intermediate size of 120 000/150 000 tonnes deadweight is also evident which, in addition to carrying crude oil on shorter routes might well be used to trans-ship oil or carry products into the U.S.A. at draughts up to 16 m. A further range 70 000 to 90 000 tonnes deadweight has also been ordered in some quantities mainly as secondary carriers but this could become an uneconomic size when segregated ballast requirements have to be met. The final category are ships between 20 000 and 50 000 tonnes deadweight which will be used increasingly for redistribution services as crude oil transportation is taken over by larger vessels. The size ranges for bulk carriers can be identified by reviewing the standard designs developed by shipyards throughout the world and the tonnage on order at the end of 1972. These start with a class of vessel between 20 000 tonnes deadweight up to 40 000 tonnes deadweight, suitable for world wide deep sea trading with a limited draught of up to 11 m, with efficient cargo gear and hatch arrangements to give maximum trading flexibility for a wide range of bulk cargoes. An intermediate size of between 55 000 tonnes deadweight and 80 000 tonnes deadweight with dimensions to suit the transit of the Panama Canal with a maximum geometric draught of up to 14 m. The larger category are generally over 120 000–140 000 tonnes deadweight covering pure bulk carriers, OBO ships and oil/ore carriers with draught limitations in the vicinity of 16 m, so that they are capable of operating from a reasonable number of ports. They are normally employed for the carriage of coking coal and iron ore.

The remaining types of vessel, although not so significant in terms of tonnage, can have an appreciable influence on installed power figures for prime movers. Dry cargo vessels excluding bulk carriers consist of mainly multi-deck freighters and cargo liners with a recent containership content. In 1970 these categories accounted for 98 million tonnes deadweight of the world fleet and are expected to increase to about 114 million tonnes deadweight by 1980. This reflects an increasing productivity in tonnage as the effect of containerization and unitization begin to have an impact. If it is assumed that containership tonnage is equivalent to five times the tonnage of other types of cargo carrier, the cellular containership will be responsible for over 40 per cent of the tonnage moved. These vessels have now progressed to the third generation carrying over 2000 × 20 ft containers at speeds up to 30 kn. The trend is to operate a liner service, calling at a small number of ports which can make maximum use of water or land feeder services to achieve final distribution. The U.S.A. and Japan are major consumers of natural gas, a pollution free fuel which, in the former case, is being used to replace diminishing national reserves with discoveries from abroad. Ships in service and on order at the end of 1972 represented a capacity of 2·9 million cubic metres, the most popular size being in the 120 000–125 000 m^3 range. It is estimated that up to an equivalent of 100 vessels of this size could be in service by 1980, with a further 50 delivered by 1985. The projected tonnage is about 8 million tonnes deadweight by 1980 for all types of liquefied gas carriers.

Newbuilding and Machinery Trends

To enable machinery trends to be considered, a newbuilding forecast was made to estimate average demand per annum for the three five-yearly periods between 1970 and 1985 (Table II). The scrapping rates have been predicted from the Maritime Transport Research replacement demand models(1) for tanker and dry cargo plus non-cargo carrying vessels and modified with reference to the Booz-Allen Report(3) to provide a breakdown into the various fleet classes. The results are presented in Fig 2 with historical completions and predicted deliveries from existing orders added for information where appropriate.

The total power installed per year for each class of vessel was obtained by considering the specific power trends in kW/tonne deadweight or kW/grt as appropriate (see Fig. 3) in conjunction with the assumed deliveries indicated in Fig. 2. Where the ship type is well developed a steady trend can be determined, but the container category, where each generation has seen a jump in specific powering, is closer to a step function and an approximation has had to be made. The other category subject to wide fluctuation is the non-cargo and miscellaneous which covers such craft as high powered icebreakers.

Types of Machinery Installation

Once particular types of ship, with associated size and speed, have been identified, there is generally a most popular machinery installation in a given power range. This in turn suggests it is possible to study the plant appropriate for each power range and modify the installation to suit the ship types requiring powers of this order. In considering the changes necessary to adapt machinery installations to each particular type of ship, various developments can be identified and studied separately. Fig. 4 shows the type of main machinery in the categories steam and gas turbine, medium and slow speed diesels, for various types of ship, in power installed per annum with an indication of the possible position in 1985. The trend is summarized in the world fleet totals in Fig. 5.

TABLE II—NEW BUILDING FORECAST

	Million tonnes deadweight				M. tonnes	MGRT.	M.dwt. & MGRT
	Oil Tankers	Bulk Carriers	Dry Cargo	Con-tainer	Liquid Gas	Non-Cargo & Misc.	Total
1975 Fleet	225·5	117·2	98·7	6·6	2·8	24·0	475
1970 Fleet	145·8	73·0	97·8	0·5	1·1	17·9	336
Difference	79·7	44·2	0·9	6·0	1·7	6·1	138·6
Scrapped 70-75	19·6	7·5	21·2	—	—	4·0	52·3
Total demand	99·3	51·7	22·1	6·0	1·7	10·1	190·9
Average demand p.a.	19·9	10·3	4·4	1·2	0·34	2·0	38·2
1980 Fleet	349·2	188·0	100·2	13·3	7·6	32·1	690
1975 Fleet	225·5	117·2	98·7	6·6	2·8	24·0	475
Difference	123·7	70·8	1·5	6·7	4·8	8·1	215·6
Scrapped 75-80	27·1	7·2	18·0	—	—	3·4	55·7
Total demand	150·8	78·0	19·5	6·7	4·8	11·5	271·3
Average demand p.a.	30·2	15·6	3·9	1·3	1·0	2·3	54·3
1985 Fleet	488·7	301·7	100·9	21·4	13·6	42·9	969
1980 Fleet	349·2	188·0	100·2	13·3	7·6	32·1	690
Difference	139·5	113·7	0·7	8·1	6·0	10·8	278·8
Scrapped 80-85	34·2	12·7	17·7	—	—	3·3	67·9
Total demand	173·7	126·4	18·4	8·1	6·0	14·1	346·7
Average demand p.a.	34·7	25·3	3·7	1·6	1·2	2·3	69·3

SELECTION OF MACHINERY

Many interrelated factors effect plant design and the selection of machinery.

Trade of Ship

The trade of the ship determines to a great extent service speed and limitations on dimensions. It defines the flexibility of operation needed and this, together with the other factors, influences the power requirements and rev/min selection. Projected days at sea per year and time spent in port are related to the type of trade and route used in service. The resulting reliability required and service needed for maintenance and supply of spares are also influenced by the trading route.

First Cost

First cost varies according to market conditions so that at any particular time it is difficult to make a comparison between various items, unless there is a significant difference. Small differences fluctuate with time so that when comparing two installations this should be considered. The building of series of ships and the resulting batch production, assisted by a high degree of standardization in equipment and suppliers, has a considerable impact on the first cost per vessel. When it is possible to standardize on cylinder bore and pump sizes, economies are made in material and production costs right down to items such as spares.

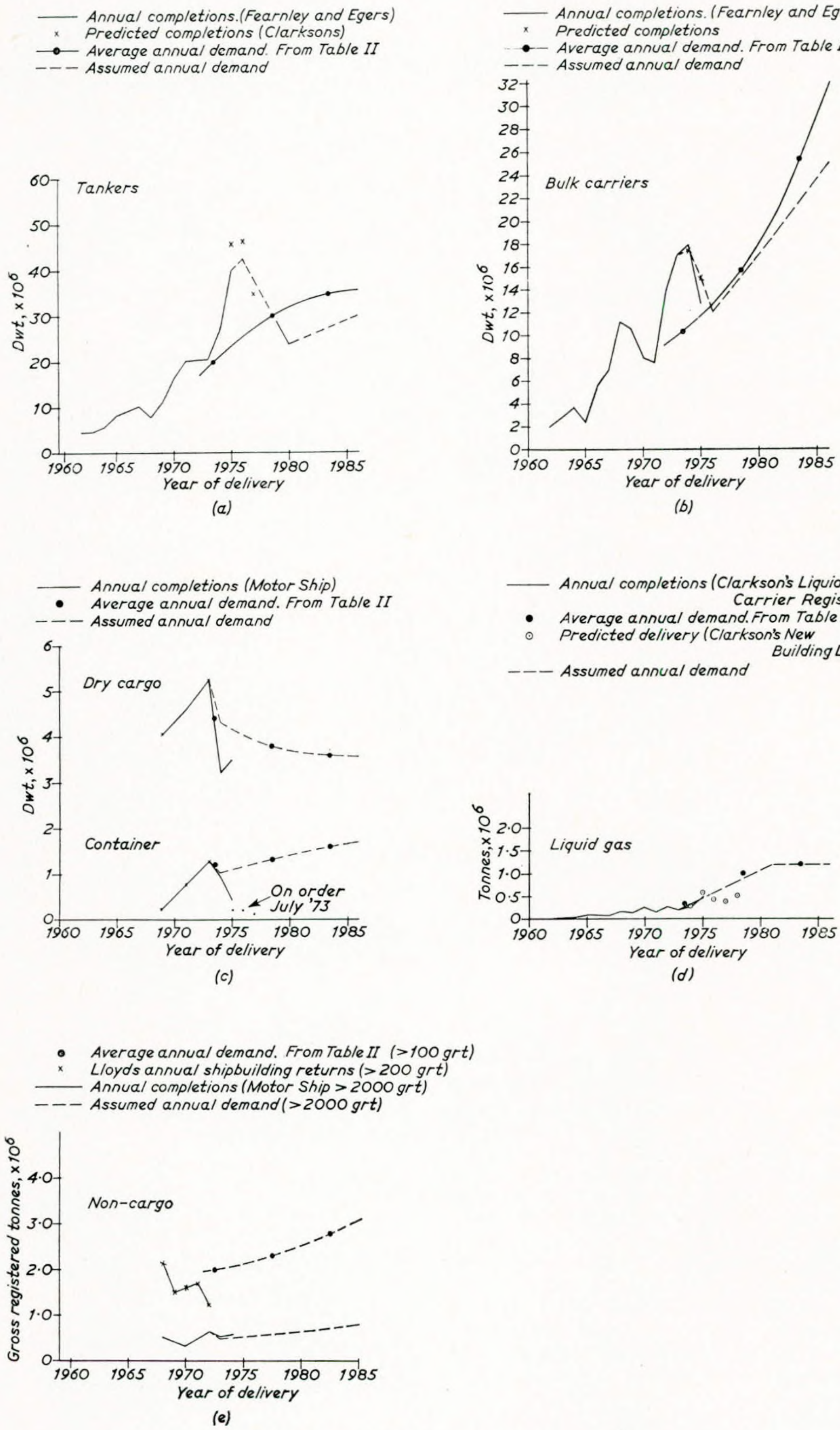

FIG. 2—*Annual requirements for new ships*

Financing

Financing arrangements such as grants, terms of payment, credit and interest rates have a considerable influence on the significance of first cost. They change the balance between the net present value of the investment and effect the result of a comparison between these and operating costs. This is well illustrated by the fact that complexity is at its greatest when grants are high and interest rates low.

Installation Costs and Facilities

Apart from the first cost of selected equipment, the facilities in the yard in which the ship is to be built have an influence on the installation costs and the ability to lift large assemblies complete into the ship. Selection of equipment to allow packages to be delivered to the yard or built up in the yard, prior to shipping, have a considerable influence on installation costs. When comparing different items of equipment, installation cost studies must include the differences in support arrangements such as structure and all services including uptakes and intakes. The capability of the yard in which the ship is being built will also, to a degree, determine the machinery installation,

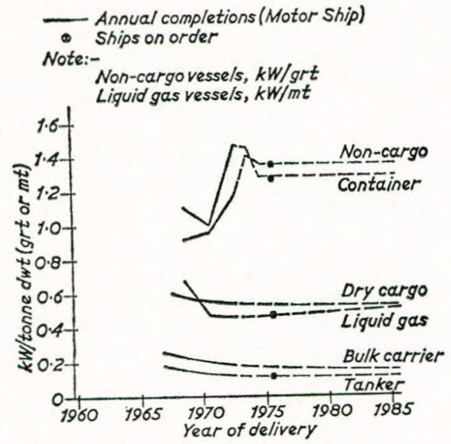

FIG. 3—*Specific power trends (kW / tonne dwt)*

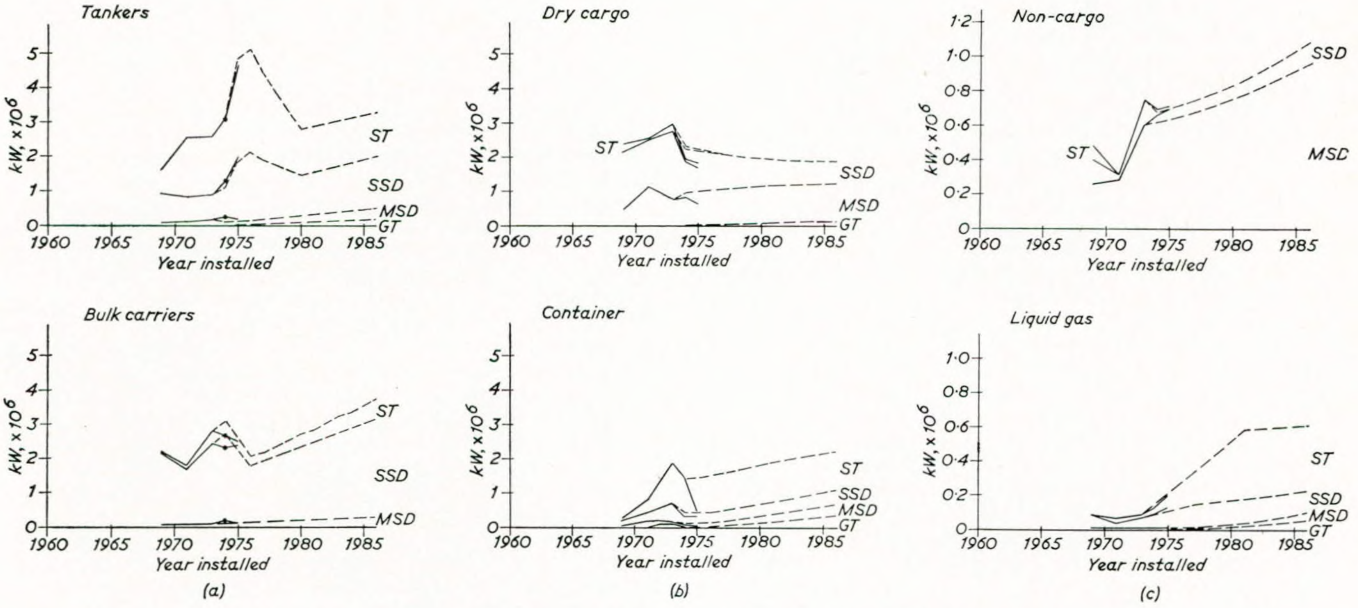

FIG. 4—*Main machinery power installed per year*

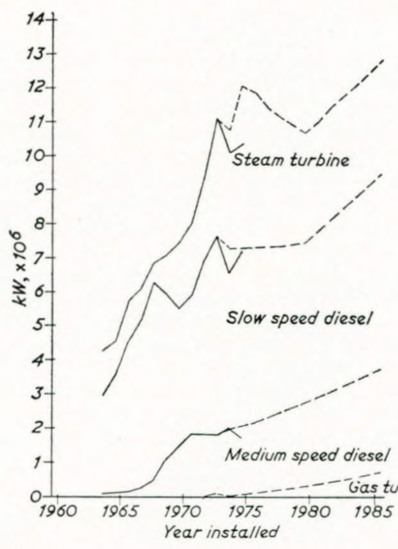

FIG. 5—*World fleet machinery trends—Power installed per year*

depending on the previous experience available and the skill of the staff in design, quality control and planning.

Hull Design and Equipment

The economy of any particular machinery installation can be effected by the space occupied and location required, weight of total installation and fuel consumption per day. The flexibility of operation and type of ship also effect the size of the machinery installation, particularly if there are significant power requirements for cargo handling or ship handling. It also depends on whether the opportunities offered for saving space and weight can be converted into useful cargo capacity because, in a number of cases, such as certain sizes of tanker, it is difficult to convert the reduced light weight into cargo deadweight.

Cost of Consumables

The rate of consumption of consumables such as fuel and lubricating oil and certain categories of spares together with the costs and quality of these items on a particular route can influence the selection. If there are only lower grades of fuel oil available it is unlikely that certain types of machinery such as gas turbines and medium speed diesel can be considered.

Availability and Maintenance Costs

The cost per day of operation resulting from first cost financing arrangements, manning and other factors change attitudes towards availability. If these costs per day are high as they are in the case of large tankers, then maximum availability is clearly indicated. Maintenance costs should always be at a minimum but can effect availability if the work content begins to overlap with the intended operational time.

Crew Numbers and Training

The availability of skilled crew will also be a factor and could determine a policy of limiting the different types of equipment installed to ensure that staff moving between ships quickly become familiar with an installation. Experience in particular types of machinery might dictate a continued installation of this design and limit the choice of certain auxiliary plant. There are examples of owners leaving out large waste heat systems with the associated turbo-alternator because they consider their staff are not familiar enough with this feature and that its introduction would only reduce reliability.

Insurance and Safety

Insurance premiums are a significant operating cost and should ultimately be linked to design features. Twin-screw propulsion, "get-you-home" powering capability, emergency generator capacity, the installation of inert gas systems and the use of fixed fire-fighting systems on deck all contribute to improving safety. Collision avoidance and anti-standing information, or features which improve braking and steering, should also be given careful consideration. Designs should always review the features which improve safety to get maximum availability, but some further incentive is required, from the insurance industry.

TRENDS IN MACHINERY INSTALLATION DESIGN

Engine development has followed a similar course to that already described for ship types in that there has been an increasing degree of specialization and improvements in efficiency in terms of power output per unit weight. Fuel economy has become more important as bunker costs increased because of the international supply position. This will however, be approached with some caution to ensure that ship availability is not reduced.

The reserves of crude oil in the Middle East represent 75 per cent of the uncommitted reserve so that this area will be the major supplier of fuel oil in the 1980's.(4) The main characteristics of this crude oil are generally of intermediate values with vanadium and sulphur contents acceptable to machinery designers. Light marine fuel oil of 370 cSt (1500 seconds Redwood No. 1 at 100°F) is now the most widely used marine fuel representing a reasonable balance between fuel cost and increased operating costs. Its cost is about 65 per cent of that of marine diesel oil and about 104 per cent of heavy marine fuel oil with a viscosity of 850 cSt (2500 seconds Redwood No. 1 at 100°F).

Fuels used in land based installations will increasingly be selected with a view to reducing air pollution. This means that low sulphur fuels such as those from African and Indonesian crudes will be used for inland markets. The demand for low sulphur fuels will not be met entirely from these sources and refineries will have to treat supplies from other sources. As a result of this, there will be a price differential between low sulphur and high sulphur fuels, although this should have little cost impact on marine fuel costs, where air pollution will not be so important. It is not anticipated that the maximum sulphur content of marine fuels will change, but the average will undoubtedly increase.

The aircraft type gas turbines require special fuel characteristics and these are not at present generally available at bunkering ports. The progressive change to distillate fuel by the navies of the world will accelerate the requirement for heavier distillates. This should mean that storage and handling facilities will progressively become available and that suitable grades, with a slightly lower cost than marine gas oil, can be used for early applications.

It is not expected that, within the next ten years, there will be any radical change in the types of machinery used in ships and that new developments will be concentrated on improving the reliability of installations, with ships regarded as an integral part of a total transportation system.

Financing costs, such as depreciation and interest charges, together with insurance premiums, can be over 70 per cent of the total operating cost for a large tanker. The financing factor for the shore facilities and remaining components in the transport system are generally even larger, so that utilization and availability are at a premium. Continued difficulties in recruiting and retaining seagoing staff plus further increases in manning costs will lead to marginal reductions in manning scales. This will require the application of techniques at the design stage which ensure a higher degree of reliability and make operation and maintenance easier. Studies will be made at an early stage of the design process, using machinery arrangements and models, together with work study techniques to establish and select from alternative routines. Increasing "in water" inspection will effect certain design features, such as stern gear and ship side openings. Planned maintenance programmes will be compiled together with documentation showing operational routines and overhauling tasks. More maintenance will be carried out at sea by squads, to keep ships in operation for the maximum possible period of time, and consideration given to simplifying the overhaul and maintenance to minimize costs. This is particularly important, as shore repair costs are now escalating at 15–20 per cent per annum. Maintenance schedules will be compiled for individual units and components which require replacing at given intervals defined. It will then be possible to categorize equipment into that overhauled by replacement, and for which removal routes will be provided, or alternatively repaired by replacing components on board. Machinery will be designed on a modular basis, not only to reduce installation costs, but to facilitate removal. Static elements will be favoured when thermal efficiency is to be improved or purification required. Part of the feed-back from maintenance systems will be data on failures so that, by co-operation between organizations, the information needed for a fuller mathematical analysis of reliability will progressively become available.

A key design objective will be to simplify installations, so that they are more readily understood by the operator, and training programmes introduced for operators to keep staff familiar with the limited number of machinery items used. This will be greatly assisted by the trend towards building longer series of ships based on the same specification and design. In fact there will be a reduction in the number of equipment designs available because of the increasing research and development costs involved in introducing new types. Each major change in the design of equipment will be shore tested with a comprehensive programme, to prove both performance and reliability, before it is used in a shipboard application. The past practice of giving new equipment a slightly extended test run will not be acceptable. Competition over the last ten years has led to a progressive reduction in material quality and design margins, accompanied by attempts to uprate equipment. This trend will be reversed, with proper attention given to key areas both in these respects and to provide a basis for a higher standard of quality control. The degree of quality control possible is in part determined by the definition provided in the design stage, starting with the selection of material and process specifications and continuing through into machining tolerances or surface finish so that the interchangeability of components is assured. A movement towards international standardization of units and components will greatly assist repair by replacement techniques and make interchangeability more readily attainable. This will be accompanied by more precise classification and statutory requirements based on rules which are common to many authorities.

One of the limitations designers will begin to meet is the increasing cost of scarce materials(5). If these are defined as elements which are present in the earth's crust at average concentrations of less than 0·02 per cent by weight, then most of the non-ferrous metals are included. In addition to this, materials such as copper, lead, zinc and tin have been used for generations because they are easy to cast and work. Their ability to form a range of alloys which are corrosion resistant, or can be used to protect iron and steel from atmospheric attack, has led to them being used extensively in the marine environment. In future they will have to be progressively replaced by more plentiful metals such as iron, aluminium, magnesium and titanium. In the case of steel there will be an extensive use of plastic coatings, or it will be replaced totally by plastic in suitable applications. Despite these limitations, designers will continue to develop machinery with high ratings, to secure their competitive position by reducing the power/weight and power/cost ratios, while at the same time bringing down the number of components for a given output. Providing this is done within the limits described above, this should not necessarily be accompanied by operational difficulties which reduce availability. As ratings increase operators will tend to use equipment at a progressively larger percentage below the maximum continuous rating quoted by the engine designer, to reduce maintenance costs and improve the availability factor.

As solid state technology and miniaturization advance, the installation of controls and instrumentation will become more extensive. This will be partly to assist in reducing watchkeeping personnel, but also to monitor the more highly rated machinery, as operation away from design conditions will lead to a rapid increase in maintenance costs and the probability of breakdown. Analysis of data will be used to review performance by comparing specified values with those actually achieved. As more information becomes available, trends will be used to give fault prediction or identify components requiring maintenance. This will reduce the amount of overhauling done in anticipation of difficulty and develop planned maintenance to a stage where work is only done when needed. In parallel with this other areas of ship operation such as navigation, ship handling, cargo handling and administration will be under review so that it will become possible to integrate and centralize the control of various aspects of ship operation. This could lead to all control and display information being brought back to one central operations room adjacent to the bridge. A progressive reduction in the cost of electronic components and improvements in computer techniques will make it possible to control some areas of the ship operation with small computers. The current trend towards electronic control systems provides a basis for the application of on-line digital computers, once integrated circuits have reduced both hardware and software costs. The installation would have to be fitted with environmental protection and be designed to meet stringent service requirements with further protection being provided by incorporating fault analysis procedures.

The design process itself will start by considering a range of installations in a short period of time using economic criteria in the selection of equipment. System designs will be based on, not only theoretical considerations, but feed-back from ships in service, giving loads and service factors. Analogue computers will be used to simulate systems and control action, when applications take developments outside previous experience, and will be detailed enough to provide initial control settings for the commissioning of equipment. A dynamic equipment simulation will be used to test key control systems before they leave the suppliers works. When calculation or simulation is not possible, stress and flow models will be used to provide data. As in all fields, there will be increasing emphasis on design for production, placing considerable stress on reducing material costs and work content during manufacture. Layout will be increasingly influenced by the need to provide advanced outfitting opportunities, adequate access for equipment during shipping and a high degree of pre-manufacture of outfit items. Batch quantities of standard components, to gain maximum output or purchasing power, will be required. Environmental aspects will become increasingly important, but this will not be confined to overboard discharge of cargo and effluents. Noise and vibration, within both the accommodation and working areas, will be given close attention. The mechanical balance of units will be reviewed, mounting arrangements investigated and acoustic insulation considered in some detail. Investigations will be made to find empirical correlations between the magnitude of noise and vibration sources and the resulting output at various locations in the ship. The vibration characteristics of systems will be considered in more detail including the effect of failures in critical components.

The detail examination required at the design phase and the depth of these investigations, including the need to consider production costs, suggest that the number of installation design organizations will get progressively smaller. In addition to this, more pre-contract design, in the form of design studies, will be undertaken, so that important decisions are reviewed with sufficient data available and not overtaken by the discipline required in a production programme.

FUTURE DEVELOPMENTS IN MACHINERY FOR HIGHER POWER RANGES

The comments in this section are confined to high power vessels whose draught limitation is imposed by the depth of channel they have to navigate. A propeller speed of 60 rev/min is used because it is regarded as the lowest practical limit in the period considered and has found to be an optimum in some investigations(6).

Steam Turbines

The basic technology for increasing the output from steam turbine designs is already available and can be achieved with little increase in the size of the plant. Development efforts will be concentrated on simplifying the installation, making it easier to operate by choosing components which reduce system turn-down. Attempts will be made to package and automate parts of the boiler equipment and feed system, so that they can be pre-assembled and set up ashore in the same way as diesel machinery. Two basic types of cycle will emerge, the first and simplest being for the higher power ranges. Installations of this type will be based on twin boiler straight cycles with steam conditions of 62·8 bar/510°C, with undiluted funnel up-take temperatures of 140°C and flue gas CO_2 content of 15½ per cent. Three feed heaters, including one in the high pressure part of the feed system, would give a service fuel consumption of 280 g/kWh at 29 420 kW, using a heavy marine fuel oil. The second type of installation would be based on a re-heat cycle, with twin boilers and steam conditions of 101 bar/510°C. The remaining features would be basically as described above, except for the use of five feed heaters in the cycle giving a service fuel consumption of 255 g/kWh. There is a gradual improvement in non-bled steam rate of about 15 g/kWh, for each 10 MW increase in power and a parallel reduction in fuel rate. It is not expected that there will be any significant increase in steam conditions except for the application of these re-heat units and this will only be done once the reasons for the unreliability of existing installations have been established.

Gearing Design

As main wheel diameters of 4·5 m are approached, alternative gearing configurations are investigated before reaching the limit, which is normally of the order of 5 m. If a propeller speed of 60 rev/min is used as a basis, a cross-compound set, with dual tandem double-reduction gears, using a main wheel of 4·5 m would be capable of transmitting 19 120 kW, with hard on soft, and 23 535 kW with hardened primary wheels. Limited increases above these powers are possible by changing the power distribution, but significant improvements require triple-reduction gearing on the high pressure turbine train. If this is done powers above 29 420 kW can be transmitted to a shaft turning at 60 rev/min. The limit requiring a change to triple-reduction is reached at about 36 775 kW when the propeller revolutions are 80 rev/min using "hard on soft" materials. There are currently developments towards nitriding primary wheels, so that a smaller main wheel can be used, say 4·2 m, with the power transmitted increased to about 41 920 kW at 80 rev/min. Epicyclic secondaries will be used in some installations, primarily on the basis of cost advantage rather than the marginal reductions in engine room length they make possible. In general it is not anticipated that gearing will limit the power output from future steam turbine sets.

Diesel Machinery

The main development in diesel machinery will be to take further advantage of improved turbocharger efficiencies and the introduction of two-stage turbocharging, to increase the turbocharger pressure ratio from the current values of 3·5 to 1. Recent developments in diesel machinery have introduced design features in components, such as cylinder heads, liners and exhaust valves, which allow further increase in output without encountering thermal stress difficulties. More detail analysis of mechanical stress in moving parts and frames has also created margins in the mechanical design. These will be used to raise the rating of machinery, so that the output per unit length and unit weight will be increased, but this will be done without increasing significantly the ratio of maximum pressure to mean pressure. The specific fuel consumption will therefore, remain basically at the current level of 216 g/kWh when burning marine fuel oil. The increased cost and complexity introduced by two-stage turbocharging will mean that its use will initially be restricted to larger bore engines of the slow speed type. Table III shows the increases in output that might be achieved as a result of these developments.

TABLE III—TYPES OF DIESEL MACHINERY IN SERVICE

Engine Data & Performance	Slow Speed (Two stroke)		Diesel Machinery Type Medium Speed (Four stroke)		High Speed (Four stroke)	
	Current Value	1985 Value	Current Value	1985 Value	Current Value	1985 Value
Bore (mm)	1000	1100	550	650	250	300
Stroke (mm)	1900	2000	550	650	300	300
b.m.e.p. (kgf/cm^2) at m.c.r.	12	20	18	25	15	20
Level of Output/cylinder at m.c.r. (kW)	2940	6620	800	1690	180	365
rev/min	110	105	450	400	1000	1100
Number of cylinders	12	12	18	18	16	18
Level of total output kW at m.c.r.	35 300	73 550	14 710	29 420	2 940	6 620
Level of total output kW at c.s.r. (about 15% derating)	29 420	62 520	12 500	25 000	2 500	5 515

Ability to burn marine fuel oil of at least 370 cSt (1500 seconds Redwood No. 1 at 100°F) reliably will determine the rate of development. The anticipated movement in the output of slow-speed and medium speed engines indicates a similar order of improvement which will tend to limit further increases in the market share of the medium speed units, except where engine room height is an important factor. In the higher power range for tankers and bulk carriers, engine room length is a prime consideration so that although the slow speed diesel will improve its competitive position against the steam turbine, requirements for cargo handling drives or cargo heating means there are still certain disadvantages. The same is true for products carriers, where space restrictions and the ratio between propulsion power and the output for other services are in favour of the medium speed diesel, provided there are limited heating requirements. In the high power range, the slow speed diesel has recently recovered some of the market taken by the steam turbine and these trends, together with a prediction of the future distribution in market share between competing prime-movers, are shown in Fig. 5.

In addition to developments leading to increased output, considerable effort will be made to reduce noise levels and improve the balance of diesel machinery. This will include the fitting of weights and secondary balance equipment as a standard feature. A major design objective will be to achieve routine maintenance programmes which allow major overhauls to be carried out during docking. This will mean an additional investment in tools and equipment, so that work can be carried out on a number of units at the same time.

For the higher power, single-input medium speed diesel drives, epicyclic gears can be attractive, with powers approaching 25 750 kW being transmitted to the shaft running at 60 rev/min using an annulus of about 4·5 m diameter. A twin-input installation, with machinery at 400 rev/min, delivering 30 900 kW to a propeller running at 60 rev/min, would require a single reduction gear with a main wheel diameter of 4·8 m. Dual tandem, double-reduction gears or idlers between the pinion and the wheel are required for high powers.

Gas Turbines

The gas turbine has two basic advantages for shipboard application, the first being its ability to produce large powers with low weight in a confined space and second is the ease with which it can be remotely controlled and operated without supervision. In vessels where fuel costs have become a smaller part of the total operating cost, the use of gas turbines will be considered. This applies when a high power is required for ship types in which there is a tendency for speeds to increase and cargo capacity can be improved by taking advantage of the reduced engine room volume. For example recent consideration of segregated ballast for larger tankers could change them from weight limited to volume limited ships. Movement in fuel costs and the difference in costs between marine fuel oil and distillates will have a significant effect on the potential applications.

The industrial gas turbine which could burn heavy grades of fuel following further developments in fuel treatment will have a competitive fuel rate, providing it is closely matched to the propulsion requirements of the vessel and not derated. Its best application will be in trades where relatively high powers are required so that the installation works at full output for extended periods with a regenerative air heater to improve cycle efficiency.

It is doubtful whether combined cycles will be adopted because, unless they are simple steam systems of the "helper" type, they immediately sacrifice the simplicity of the gas turbine. Sets are already available capable of 44 130 kW which, with regeneration, gives a fuel consumption of 279 g/kWh using a pressure ratio of 9 : 1. An increase in turbine inlet temperature of 100°C from current values improves efficiency by 2½ per cent and would make it necessary to increase the pressure ratio to optimize the cycle so that H.P. and L.P. compressors might be introduced. The resulting reduction in size of the turbine rotor would simplify replacement and maintenance. The industrial gas turbine can burn the same grades of fuel as those currently in general use on diesel and turbine installations as, in general, the vanadium and sodium content are within acceptable limits. The industrial gas turbine should find applications in larger ships when the general arrangement allows the space saved to be used in the carriage of cargo, particularly if the installations can be arranged so that pumping and electrical requirements can be met from the main units. Increased turbine inlet temperatures with regeneration could reduce fuel consumption to 230 g/kWh.

There could be some problems in introducing units derived from aero-engine designs, because of marine environmental and vibration difficulties, together with the higher grade of fuel required by this type of machine. This could be partly offset by the large investment already made by the aircraft industry in the initial design, followed by the development in shipboard applications sponsored by world navies. At the present time, these units present servicing problems and gas generators require replacing more frequently than normal classification survey intervals. It might even be necessary to keep additional gas generators as shore based spares and the overhaul of these units would be undertaken ashore.

The latest generation of turbofan units needs significant changes to adapt them for marine use and makes it possible to introduce more suitable materials when the conversion is being done. In 1975 units will be available capable of up to 22 065 kW with a fuel rate of about 290 g/kWh based on existing aircraft engines. Powers above 22 065 kW are possible, but the machinery is becoming increasingly complex so that it is more likely that basic components will be taken from these sets and used to design marine units, rather than simply adapting the aircraft engines. Component life could then be made longer and a lower grade of fuel, perhaps marine diesel oil, considered, together with a degree of regeneration. Compression ratios could advance to 15 : 1, together with higher inlet temperatures made possible by the introduction of blade cooling. The air quantities would be significantly reduced, assisting with the ducting problem on gas turbine installations, and consumptions of 230 g/kWh might be attained. In the immediate future this type of unit is more likely to be used in vessels such as container ships and where there is a high long term power requirement and space is valuable.

It is considered that the design approach used in the industrial gas turbine and the adapted aero-engine units will progressively converge until there is a unit specifically designed for high performance marine use.

Transmission of gas turbine output can be achieved with gearing similar to that already discussed when considering steam turbines. The limits of various arrangements are similar when a twin-input, single-output gearbox is considered, because the rotor speeds are of the same order. Reversing will probably be achieved by either fitting controllable pitch propellers or using electric transmission. Some initial installations might use a single gas turbine with outputs approaching 29 420 kW with the propeller running at 80 rev/min. A single-input gearbox, using a variation on existing double-reduction, hard on soft, arrangements can transmit this power with a main wheel of 4·5 m diameter.

Nuclear Power

Later in the decade, interest in nuclear power will be revived as an alternative fuel source when hydrocarbons become more expensive as a result of competition between consumers. High capital cost will still be a major disadvantage and vessels of this type will need a high utilization factor at large powers to be justified. National refuelling facilities will have to be considered with berths and cranage to suit the largest ships. Early installations will be based on pressurized water reactors using the technology developed for military applications. Despite this re-appraisal, no significant applications are foreseen in the period, as fuel oil will remain available for shipping and the main emphasis in nuclear power will probably be land based generation.

Propellers and Shafting

Attempts will be made to improve the propulsive efficiency of vessels by obtaining a better understanding of the propeller/hull interaction and the introduction of new propeller systems. Propeller revolutions will be kept as low as possible, within the limits allowed by draught, and on slow speed diesel installations with highly loaded propellers ducts will be introduced. They will also be used on steam propelled tankers and ultimately fitted as steering nozzles. Each reduction in 10 rev/min improves the propulsive efficiency by $2\frac{1}{2}$ per cent, whilst the use of a duct can give increases of up to 8 per cent. A duct also makes it possible to increase the output from a given propeller design by up to 20 per cent, depending on the wake variation before and after it has been applied. Tandem propellers also offer some improvement in efficiency, but are not considered a likely development, at least until a satisfactory outrigger bearing is available.

The larger diameter propellers and lower operating rev/min found on large tankers, reduce the overall cavitation loading below that found on other types of vessels. This means that it is not likely to become a limiting factor until very high powers are required. Operating experience on the present generation of these vessels confirms that, from the erosion viewpoint, no serious problems exist. Any local erosion patches can generally be avoided by providing greater blade width, to account for the extreme conditions of loading, and careful consideration of hull form, to give the best water flow into the propeller disc and minimize cavitation problems and any associated vibration difficulties.

On a single-screw vessel running at 60 rev/min and a draught limitation of 22·3 m, the maximum allowable propeller diameter would be approximately 14 m. The power for optimum efficiency in these conditions using a four-bladed propeller would be 58 840 kW and a weight of about 170 tonnes. A redesign using the same limiting diameter, would make it possible to deliver 73 550 kW at 64 rev/min. Applying a similar design approach to a twin-screw installation, the maximum allowable propeller diameter would be 12 m with an optimum design at 73 550 kW per shaft, running at 78 rev/min. Each propeller would weigh 145 tonnes. Assuming that solid propellers are used, then a manufacturing limit of 90 tonnes finished weight should be considered when designing. The optimum design for a shaft running at 60 rev/min gives a q.p.c. of 0·79 at 30 890 kW with a diameter of 12 m, which is within the maximum determined by the draught. A family of propellers, designed on the basis of a 90 tonne weight limitation, would give an output of 42 000 kW at 80 rev/min with a propeller of 11·3 m diameter and a q.p.c. of 0·71. At 100 rev/min, the values would be 54 420 kW, a diameter of 9·75 m and a further reduction in q.p.c. to 0·63. If this approach is now applied to the twin-screw vessel, the optimum efficiency at 60 rev/min occurs at 33 100 kW per shaft, with a diameter of 11·9 m, resulting in a total q.p.c. of 0·71. At 80 rev/min, the power and diameter become 45 600 kW and 10·7 m for a q.p.c. of 0·63. These values become 58 840 kW for a diameter of 9·75 m and a total q.p.c. of 0·58 at 100 rev/min.

The figures given are approximate and are basically for four-bladed designs, although the power values would not be significantly different for six blades which are more common on larger vessels.

It is anticipated that at 500 000 tonne deadweight, consideration will be given to twin-screw installations, mainly to satisfy safety and insurance factors. The power requirements for single-screw vessels of this size with a shaft speed of 60 rev/min are about 36 775 kW at 15 kn service speed loaded, rising to 47 440 kW for 16 kn in service. If a maximum propeller weight of 90 tonnes is accepted then it can be seen from Fig. 6 that the minimum propeller speed possible at 15 kn service loaded is about 70 rev/min.

When the manufacturing limit of 90 tonnes is related to stern gear designs and after bearing load, plotted against power for a shaft speed of 60 rev/min, the specific loads are found to be near or slightly above those allowed by current classification rules. An interesting feature of this curve is the reduction in specific load, as power is increased so that the highest figure of 6·6 bar (657 kN/m^2) occurs at 30 890 kW, the lowest value considered. These figures are based on rule size tailshaft diameters and the problem can be overcome by increasing the bearing surface.

Propeller finished weight is, therefore, the main obstacle to reducing shaft speed, with bearing specific load only becoming a consideration after significant increases have been achieved in the present manufacturing limits. This is illustrated in Fig. 6 which shows the reduction in rev/min possible at a series of ship speeds for different finished propeller weights. Built-up propellers are an alternative solution, but there does not appear to be a justification for the complexity and loss of efficiency this causes, particularly as more conventional designs are

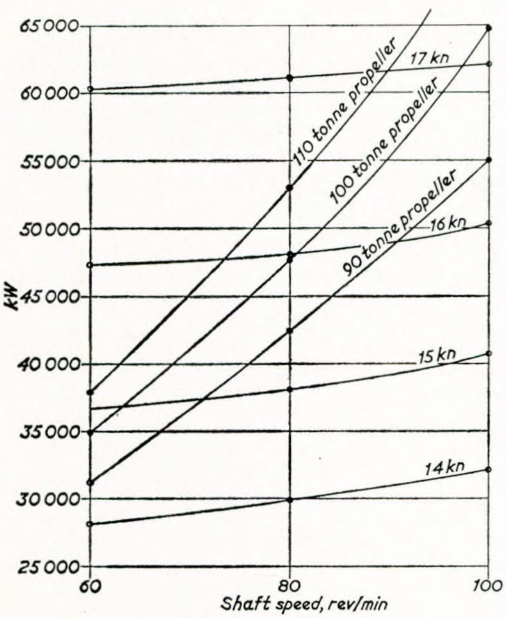

FIG. 6—*Power/shaft speed relationship for a single-screw 500 000 dwt tanker*

satisfactory for the application. For even larger vessels, in the region of one million tonnes deadweight triple-screw propulsion might be considered because, at 16 kn service speed, 69 870 kW would be required, spread equally between the three propellers. This arrangement gives a higher propulsive efficiency than either twin or single-screw systems.

Auxiliary Systems

In auxiliary systems, it is expected that electrical voltage will be increased to 3·3 kV for transmission within machinery spaces, particularly in association with electric propulsion and cargo pump drives, with gas turbine machinery as the prime mover, because of the freedom it gives in locating equipment. Electrical heating will replace steam within the accommodation area and power packs installed to provide hydraulic power for consumers outside the machinery spaces. This will displace the low quality steam and the associated maintenance problem which occurs on current installations and improve the safety of vessels by reducing electrical power distribution outside the machinery space. Apart from deck machinery, other intermittent drives such as cargo pumps and bow thrust units could be included. The demands made on auxiliary systems will also be increased by improvements in accommodation, including air conditioning and other facilities, designed to improve the standard of living at sea.

GAS TURBINE INSTALLATION

An alternative propulsion system for a large tanker was investigated using gas turbine/electric machinery. The industrial gas turbine, with regenerator and full fuel treatment plant, was selected for the reasons previously mentioned in the paper and the gas turbine/electric installation preferred because of its compact arrangement and potential advantages in maintenance and to avoid the use of c.p. propellers or a gearbox for reversing.

The machinery arrangement Fig. 7 shows the machinery accommodated in two main levels and three intermediate flats. The gearbox and propulsion motors are arranged at the engine room floor level and allow inboard withdrawal of the tailshaft. The gas turbine flat was raised as far as the size of the regenerators and exhaust gas boilers allow, bearing in mind the size and support of the casings, to make the gas turbines accessible for repair or replacement.

With the high capital cost and operation costs of a present day VLCC, it was felt necessary to ensure that maximum availability was obtainable and two gas turbine alternator assemblies were specified. Using the current General Electric range this requires two unequal size machines to allow the required power to be developed at the full machine rating and maximum efficiency.

The gas turbines selected as being most suitable were the MN-5002R B and MN-3002R with I.S.O. ratings of 20 700 kW and 8535 kW respectively when burning residual fuel. The output of the gas turbines varies significantly with temperature and, for the mean conditions on the Persian Gulf to Europe run, the power was assumed to be equivalent to 23 530 kW normal service power.

For the basis tanker of 287 000 tonnes deadweight and service power of 23 530 kW, a propeller speed of 60 rev/min can be selected, with the propeller size inside the manufacturing limits. A.C. alternators and motors were specified on a cost and efficiency basis and the synchronous motors can be started as induction motors. A direct drive motor has the attraction of simplicity but, at the chosen rev/min, is more expensive and larger than using two 900 rev/min motors driving through a twin-input, single-output reduction gearbox. (schematic diagram Fig. 8).

At this power level, 6·6 kV voltage was considered most suitable for the machines and switchgear, with regard to current and fault ratings, and allows the use of standard switchgear. The excitation for the machines is provided by the auxiliary 440 V electrical system.

Four electrically driven cargo pumps and one ballast pump all operate direct from the 6·6 kV electrical supply. The larger gas turbine alternator provides sufficient power for full cargo pumping, with the smaller machine available as standby.

A waste heat recovery system comprises three identical tubular waste heat boilers, two of the boilers being in parallel in the exhaust of the larger gas turbine. Saturated steam, generated at 12·3 bar is returned to an unfired steam reservoir and also to a package boiler. Superheaters in the waste heat boilers supply steam to the turbo-alternator for the ship's auxiliary and electrical services. The package boiler, which acts as a reservoir to any one of the three waste heat boilers, is sized so that the combined output of the steam plant will meet the occasional hot tank cleaning requirement or provide partial cargo heating.

Inert gas is provided by an inert gas generator receiving air bled from either gas turbine compressor discharge line. High pressure air is available for inerting or air purging the tanks, whenever the gas turbines are running, and no separate fans are required.

ECONOMIC ANALYSIS

When comparing different installations, the deciding factor is economics and it is necessary to quantify all alternatives when establishing total operating costs. It is difficult to obtain realistic data when an untried plant is investigated, as many assumptions have to be made on an estimated or target performance. Again, in the present economic climate, it is extremely difficult to assess realistic escalations for the various costs involved in operation. For this reason, the following analysis has been confined to the first ten years of the life of the ship and even this may appear bold under present economic circumstances.

The economic analysis is for a VLCC of 287 000 tonnes deadweight, with alternative propulsion systems of steam turbine, slow speed diesel and gas turbine/electric. The intention is to assess the sensitivity of freighting costs, for each propulsion system, to changes in fuel costs.

The method of analysis used(6) makes a discounted cash flow calculation over the life of the ship or period being considered and presents the results as Required Freight Rates. The programme takes full account of the magnitude and timing of cash flows involved in acquiring and operating the ship, including credit for the first seven years and tax at 52 per cent, a return on investment of 10 per cent being assumed. Although these factors are not so important when considering differences in installa-

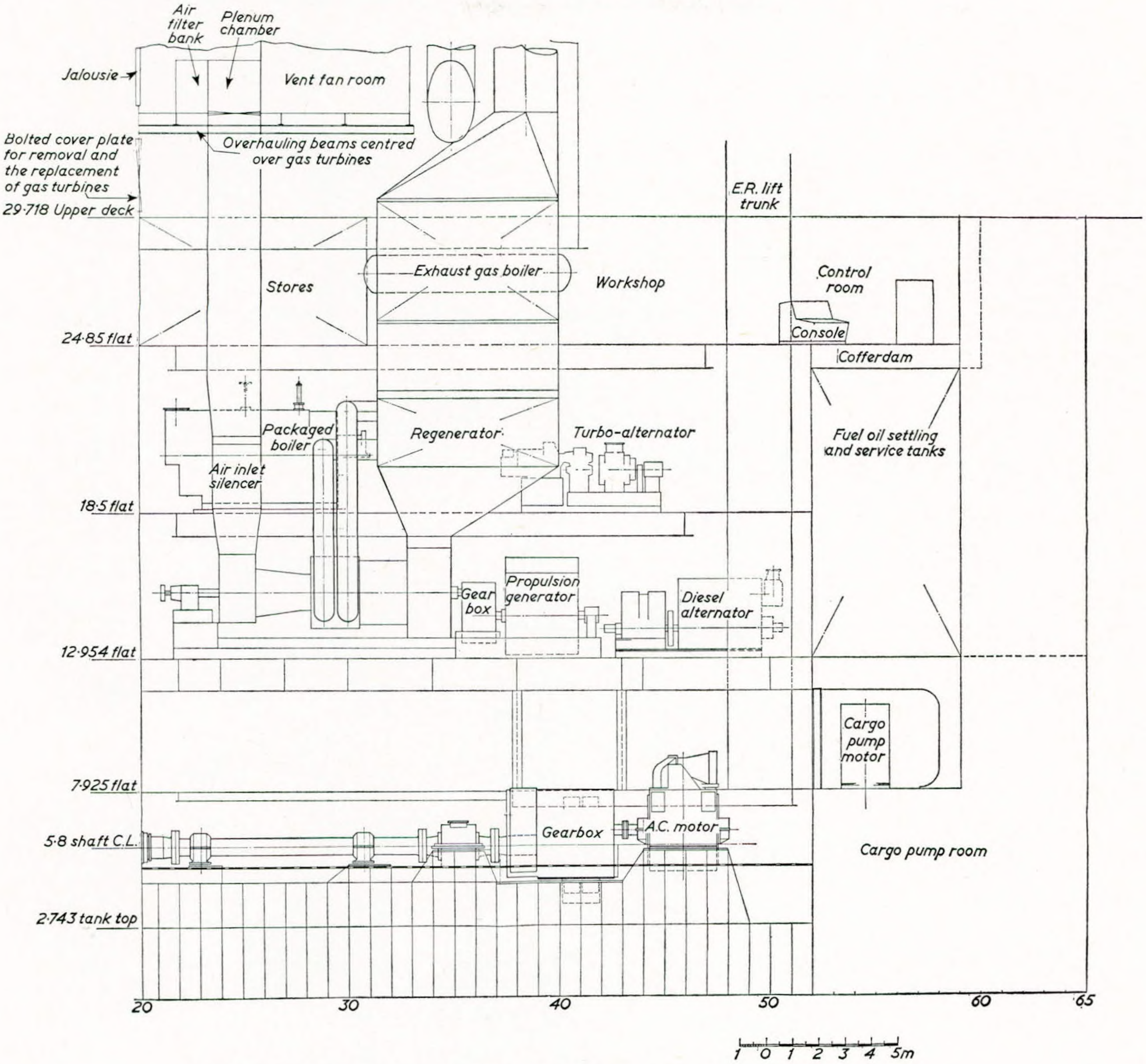

FIG. 7—*Machinery arrangement elevation for gas turbine electric 287 000 dwt tanker*

tions, particularly when ship costs are approximately equal for each installation, they are necessary when considering total overall results.

The main parameters assumed for the examples chosen are stated in Table IV and the results are plotted in Fig. 9. It should be noted that the fuel consumptions quoted for the low speed diesel include the cylinder and system lubricating oil consumptions and diesel alternator oil consumptions equated to fuel oil on a cost per tonne basis. Similarly, for the gas turbine electric installation, the fuel cost includes a margin for fuel treatment.

From the results shown on Fig. 9 it is possible to conclude the following:

1) The slow speed diesel is preferable for the VLCC and fuel range considered and steadily increases its advantage as the fuel cost increases. This is likely to lead to an increased market share for the slow speed diesel and it will also benefit from the revised thinking on oil tanker ship size which is moving in favour of the diesel.

2) The optimum speed for the VLCC decreases as the fuel cost increases. The study showed that the optimum speed varied for the different propulsion systems, the higher powered diesel being preferable for the range of fuel costs considered, whereas, for the steam turbine propulsion systems, a crossover point occurs when the fuel costs £34/tonne. Above this point the lower freight rate is obtained by the lower powered steam turbine.

An existing steam turbine installation will not necessarily benefit in overall economic terms by reducing power above the crossover point as, although the fuel costs reduce, other fixed costs, capital charges, insurance and crew costs remain fixed, and the revenue falls. However, an advantage of the slow speed diesel is that if the power is reduced, the efficiency and specific fuel consumption remain high.

3) Although the freight rate for the gas turbine/electric installation approaches the steam turbine rate at the higher fuel costs, the divergence with the slow speed diesel increases and significant further benefits, in terms of reduced cost, maintenance, crewing, would be required to make the VLCC economical.

The machinery cost for the gas turbine/electric installation was estimated to be £1·8 million higher than the comparable steam turbine installation. Some further reduction in shipbuilders' installation costs may be allowed as experience is gained, but a substantial reduction in the manufacturers costs for gas turbines, alternators, motors and control gear is required for the installation to be

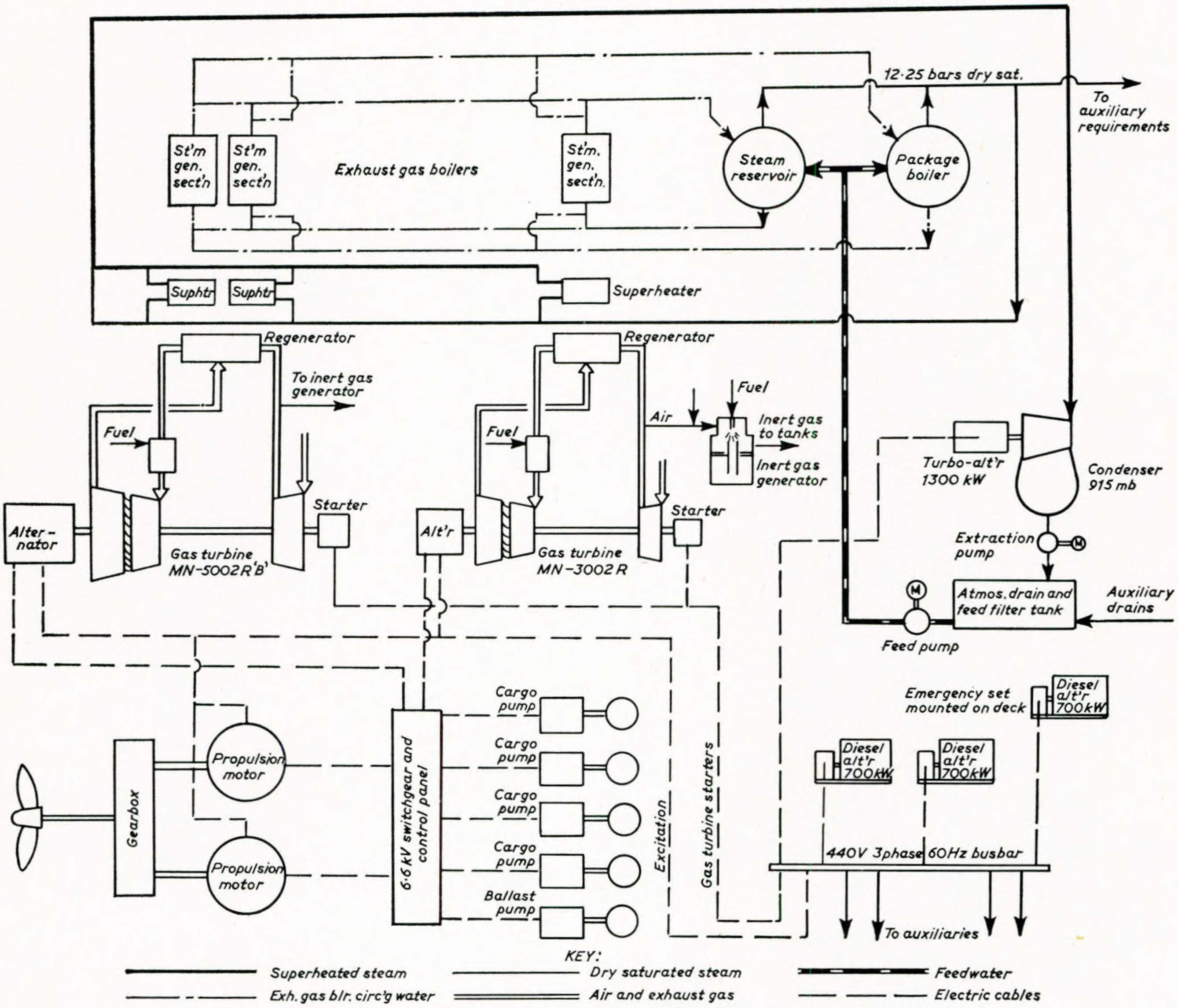

FIG. 8—*Schematic diagram of gas turbine/electric for VLCC*

TABLE IV—ECONONIC ANALYSIS FOR 287 000 TONNES DEADWEIGHT TANKER

	Steam Turbine	Steam Turbine	Slow Speed Diesel	Slow Speed Diesel	Gas Turbine Electric
Normal service power (kW)	23 530	26 470	23 530	26 470	23 530
Average speed (knots)	15·42	16·15	15·14	15·9	15·65
Cargo payload (tonnes)	280 350	279 856	279 046	278 341	280 120
Ship cost (£M)	24·7	25·0	24·7	25·0	26·5
Fuel cons. sea (tonnes/day)	175·3	196·87	141·12	158·54	173·63
Fuel cons. port (tonnes/day)	48	50	45·7	45·7	32·5
1) Fuel cost (£/tonne)	25–40	25–40	25–40	25–40	25–40
Voyage distance (naut. miles)	22 400	22 400	22 400	22 400	22 400
Days in service per annum	349	349	347	347	351
3) Crew costs (£ p.a.)	5·251	5·476	5·134	5·368	5·352
4) Fixed costs (£ p.a.)	264 000	264 000	327 000	327 000	255 000
5) Port costs per trip (£)	186 000	186 000	186 000	186 000	175 000
2) Upkeep costs (£ p.a.)	640 000	640 000	634 840	634 840	640 000
Round trips per annum	19 000	19 000	19 000	19 000	19 000

Assumed Escalation

1) Fuel cost	5%
2) Upkeep costs (maintenance, repair and stores)	15%
3) Crew costs	10%
4) Fixed costs (non-voyage costs incl. insurance and admin.)	5%
5) Port costs	10%

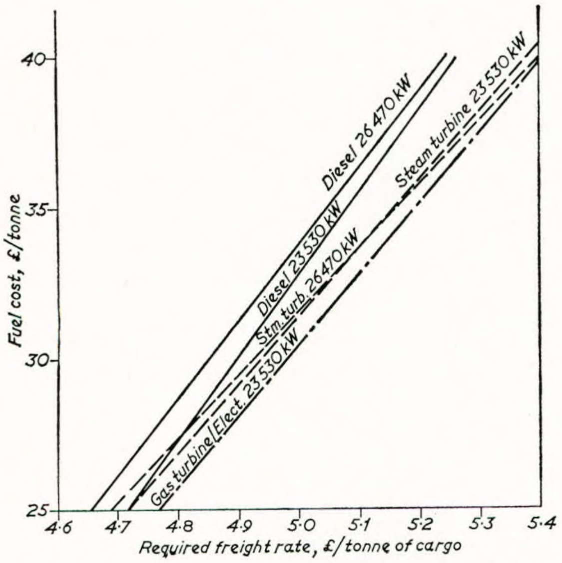

FIG. 9—*Economic analysis for VLCC with steam, gas turbine and slow speed diesel propulsion*

competitive. The manning for the gas turbine installation was assumed to be two less than for a current VLCC and some owners may be prepared to make a further reduction in this area. The gas turbine/electric installation produced the shortest machinery space length of the alternatives considered but, as the vessel was weight limited, no additional cargo capacity has been allowed. This would show as an advantage for a VLCC designed with segregated ballast. Further benefits could possibly be obtained by the adoption of cryogenic alternators and motors for the main propulsion system. These would reduce the losses in the electrical system, improving the fuel rate and reducing running costs, but any improvement here would need to be evaluated against the increased capital cost.

ACKNOWLEDGEMENTS

The authors wish to thank the Directors of Swan Hunter Shipbuilders Ltd. for permission to publish the paper and their many contacts within the industry who have given advice during its preparation. It should be emphasized that the figures given are not intended as a precise prediction, but more to illustrate a technique by which future trends in machinery requirements might be predicted.

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Discussion

MR. T. KAMEEN, F.I.Mar.E., said that he was sure it would be agreed by everyone that the authors had produced what would come to be a reference paper for the industry and one to be discussed and debated for many years to come. It gave him pleasure that the authors were such relatively young engineers and, having already made their mark in the industry, that they were prepared to devote time to preparing a paper that would be greatly valued by the Institute.

Under the heading *Crew Numbers and Training,* he was rather distressed to read of "owners leaving out large waste heat systems" because their introduction would only reduce reliability due to the lack of competence on the part of their staff. This was indeed a sad commentary on the industry and the training programme set up by owners, and he was sure that the Education and Training Committee of the Institute would want to bear it in mind.

There was possibly a printing error in the paper where it read: "As ratings increase operators will tend to use equipment at a progressively larger percentage below the maximum continuous rating quoted by the engine designer, to reduce maintenance costs and improve the availability factor". If this meant that, despite what the designer did, the operator was not going to take full advantage of it, because of the level of competence of the crew he was able to get in his ships and in order to improve the availability factor, there seemed to be something wrong again. He was not sure if that was what the authors meant.

The statement appeared in the paper that "The detail examination required at the design phase and the depth of these investigations, including the need to consider production costs, suggest that the number of installation design organizations will get progressively smaller. In addition to this, more pre-contract design, in the form of design studies, will be undertaken". Was this another step towards the standardization of ships; would owners' own design teams no longer be required in the future? Would the shipowner no longer have any real availability of ships other than those of standard designs?

MR. J. F. BUTLER, F.I.Mar.E., said that the authors mentioned the advantage of standardization of cylinder bore to suit a series of ships, and their point was fully agreed, but he suggested that there were still further advantages. Not only was the production cost of both engines and spares reduced but the immediate availability of spares was made easier and quality was improved because a single bore size made it practicable for the engine manufacturer to use sophisticated inspection equipment to ensure consistently high manufacturing standards.

The influence of shipyard facilities and installation cost was very important. If lifting capacity of up to 200 tonnes was available most medium speed four-stroke engines could be lifted into the ship in one piece and larger geared two-cycle engines could be installed in two pieces, which was the minimum practicable, for the height of such engines precluded their being transported from engine works to shipyard without division. The advantage of installing engines in the minimum number of pieces was not only the reduction in time but also the very important safety factor of reducing the risk of getting dirt into running gear bearings, which often occurred when dismantling and re-erection took place at the fitting-out quay. In connexion with installation, could the authors say whether they expected that in the future engines would be fitted after launch, as at present, or much earlier during the

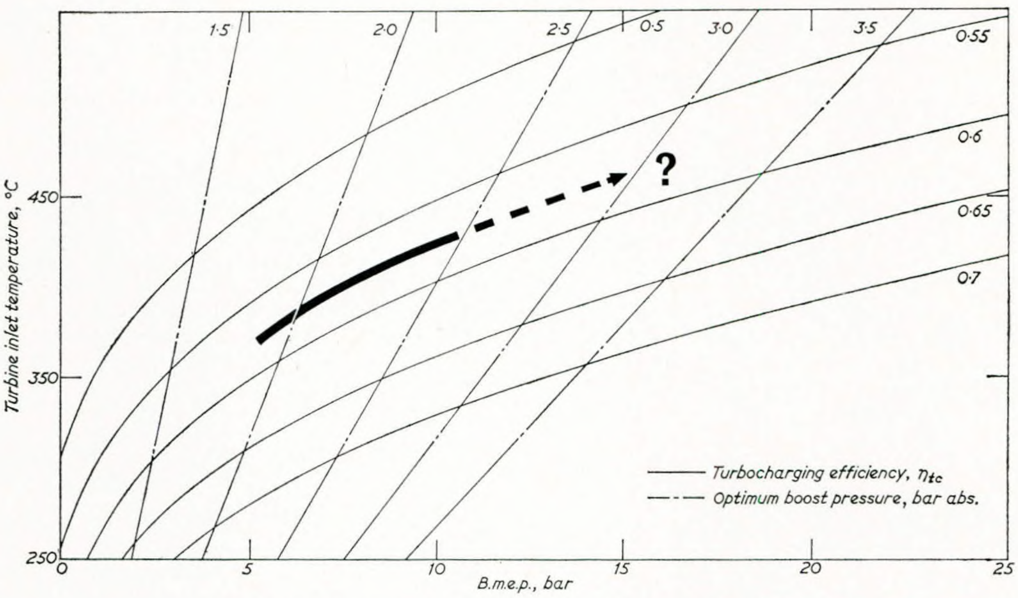

FIG. 10—*Power output of turbocharged two-cycle engine*

construction programme? Late fitting reduced capital charges, but early installation before the hull structure was complete could well reduce installation cost.

He took issue with the authors on their statement that where only lower grades of fuel were available it was unlikely that gas turbines and medium speed diesels could be considered. This certainly applied to gas turbines and to a limited extent to trunk piston diesels, but geared crosshead engines could burn any fuel acceptable to low speed diesels or even steam turbines.

The suggestion that insurance premiums should be reduced on vessels with twin-screw propulsion was most interesting. In Mr. Bowers' recent paper* to the Institute he demonstrated the tremendous reduction in off-hire time attainable with a twin-engine installation compared with a single engine. His statistical figures could in fact be extended to show that with engines which could be expected to fail for four periods of six hours each in a year the single engine installation would be stopped for 24 hours but the twin-engined vessel would only lose 5·6 minutes each year. This was a fantastic difference.

It was agreed that commercial considerations would lead to higher ratings for diesel engines, but provided the engine builder had carried out proper development testing there was no reason why the operator should increase the margin between maximum continuous and service rating. A ten per cent difference was desirable to allow for some loss of tune between routine maintenance overhauls but a larger margin than this would suggest that the engine was not fully developed.

He could not agree with the authors that two-stage turbocharging would become common practice within the next decade. Performance calculations shown in Fig. 10 suggested that it would be perfectly practicable to get up to 16 bar brake mean pressure with single stage turbocharging with the moderate turbine inlet temperature of 470°C and relatively small increase in thermal and mechanical loads above present-day values. The chain-dotted lines on the graph showed the optimum pressure ratio relating to each combination of turbocharging efficiency and mean pressure, the thinner solid lines were plots of constant turbocharging efficiency and the heavier solid line showed the present performance of an existing two-cycle engine whilst its broken extension showed possible future development. Increasing the mean pressure still further to 20 bar with higher boost pressure would call for much heavier running gear scantlings and increased bearing loads. It was unlikely that this increase would result in any reduction in either cost per kW or bulk.

Noise levels in engine rooms must certainly be reduced, particularly with multiple engine installations to make it possible to carry out maintenance operations on one engine with others running. Did the authors consider the German Standard (*See-Berefsgenossenschaft-Hamburg* 1968) of 90 db(A) for open engine rooms acceptable, or did they consider even lower levels would have to be attained? Even to get down to this level would require about a tenfold decrease in noise energy emission. On nearly all engines this would entail fitting extra silencers on the turbochargers and enclosure of much of the engine in sound absorbing casings, inside which ventilation systems would have to be provided. These refinements would, of course, cost money.

Secondary balance equipment tended to be expensive and not always reliable. Would the authors not prefer to use engines of better initial design in which the primary forces were inherently balanced and the secondary forces and couples could be balanced by choice of a suitable firing order, without the complication of extra balancing devices?

The authors' remarks on single and multiple screw propulsion installations were extremely enlightening in making clear that for large ships there was a considerable advantage in the multiple screw arrangement. Could the authors give a graph on the lines of Fig. 6 showing also the power/speed/revolution relationships for 90 tonne propeller twin and triple-screw arrangements?

MR. N. K. BOWERS, F.I.Mar.E., said that in the economic comparison of machinery alternatives shown in Table IV, the authors had concluded that the optimum or the preferable machinery was slow speed diesel. This conclusion was rather surprising, the more so because, contrary to the forward looking nature of the paper, no mention was made of the high powered medium speed diesel in the comparison. At the moment there were at least six high powered medium speed diesels of 1120–1860 kW/cylinder rating under development, all of which appeared to be suitable for propelling VLCC. It therefore seemed more than likely that two or three would eventually become successful prime movers. Furthermore a similar economic study carried out by Ohashi and Komoto, IMAS 73, concluded that for VLCC over 200 000 dwt the optimum machinery would be a twin medium speed installation (2 × 14 cylinders).

The only reason for excluding the medium speed four stroke diesel would appear to be given where the authors stated "if only lower grades of fuel oil are available it is unlikely that certain types of machinery such as gas turbines and medium speed diesels can be considered".

Curiously enough recent experience suggested that medium speed four-stroke diesel engines were capable of burning present heavy fuels at least as well and in some instances better than the large bore direct drive engines. This particular fact was one that was certainly not fully recognized and, the contributor believed, not generally known. Indeed it was only recently that the contributor's own company had enough experience with four stroke medium speed diesel engines to be able to make a firm comparison between the performance of medium speed and large bore machinery installations of similar total shaft horsepowers.

The comparison showed that the longest running four stroke medium speed diesel ship managed by the contributor's company had completed over 8000 hours of successful operation mostly on 1500 seconds Redwood fuel. During this period there had been no piston crown damage, no fouling of the exhaust ports and the liner wear had been too small to be measured accurately by shipboard gauges. Other wear rates such as those for pistons, rings and ring grooves were not checked during this period because with negligible liner wear it was thought prudent not to pull any pistons.

In a similar period the slow speed diesel ships had also operated satisfactorily on 1500 seconds Redwood fuel but occasionally there had been reports of combustion problems and in extreme cases these had resulted in crown failures and heavy liner wear. Quite recently poor combustion in one particular ship resulted in over 40 per cent blockage of the exhaust ports after only 1100 hours running. None of these combustion problems were apparent in the medium speed diesels although as with any prime mover, medium speed diesels had their problems. These included exhaust valve failures which occurred at a low but steady rate and with a completely random distribution. However, in terms of fuel at current prices exhaust valve failures added only about 0·15 per cent to the overall fuel bill. It was not therefore a very costly disadvantage and with the present concentration of technological effort in this problem area, a further improvement in valve life could be expected soon. Lubricating oil cost was admittedly higher for medium speed diesels than for slow speed diesels but the better specific fuel consumption of the medium speed diesel considerably reduced this cost disadvantage. Overall, therefore, there seemed to be little or no marked difference in the operating costs of slow speed diesels and medium speed diesel engines.

Given that there was no fuel problem and that the operating costs were about the same then, from the tanker owners' point of view, the twin medium speed diesel installation had three major advantages over other propulsive systems, including the slow speed diesels favoured by the authors. These advantages were:

1) by having twin medium speed engines and a controllable pitch propeller, the manoeuvrability, reliability, availability, and safety of the ship were enhanced considerably.
2) while loading or discharging cargo, tankers were forbidden to immobilize alongside; with twin medium speed engined tankers this was seldom a problem; medium speed engined ships could, whether at sea, at anchor or alongside, always remain mobile on one engine whilst the other might be shut down for routine maintenance, repairs or surveys;
3) a twin medium speed diesel installation could use one of the two main engines as a source of power for cargo pumping and other functions; also if electrical instead of turbine driven cargo pumps were used then boiler capacity and all associated maintenance work and costs could be reduced substantially; furthermore, only one medium speed engine of half the total propulsive power was required to drive electric cargo pumps whereas in conventional steam driven machinery installations the full main boiler output would be required to achieve the same net pumping power; the difference in "power" requirements was due to the low efficiency back pressure turbines normally used for driving cargo pumps; thus, even during cargo operations, one main engine of a twin medium speed engine VLCC could always be shut down for maintenance.

Moving on to another topic, he wondered whether the authors would care to comment on the future development of auxiliary machinery and salt water systems. From the owners' point of view there were very considerable savings to be made in this area and the subject therefore warranted some discussion in the context of future developments in machinery installations.

For example, pvc coated salt water pipes were available which could outlast the life of the ship and which appeared to have excellent antifouling properties. On the other hand, conventional galvanized steel pipes only lasted for five years and fouled easily. Even expensive non-ferrous systems sometimes failed within six months due to turbulence set up by malaligned flanges. Currently only a few progressive shipyards would offer pvc as standard whilst others would only supply them at a cost which bore little resemblance to the actual cost of coating the pipes. Would the authors comment upon the problems of fitting coated pipes of this type into the building sequence?

It was also possible to design salt water pumps that would outlast the ship. Several pump manufacturers had stated that this could be done and at least one pump manufacturer pointed to the circulating water pumps in *Queen Mary* which had lasted for approximately thirty years. Furthermore, the extra cost, in terms of the material required was not particularly high. Erosion-resistant materials were now available that did not exist twenty years ago and yet over this period there had been no apparent improvement in the life of auxiliary seawater pumps, particularly those working in sandy, muddy, or polluted waters. It would be interesting to know what improvements the authors anticipated here although it was appreciated that the most economical salt water system, including the pumps and heat exchangers must to a large extent depend on the trade for which the vessel was designed.

Although this paper was primarily concerned with future developments in machinery installations it was perhaps just worth mentioning that hull welding repairs too could significantly inflate the annual repair budget, particularly for vessels operating in ice or sandy waters. If the weld metal was less noble than the hull plating then, when the paint scraped off the weld corroded faster than the hull plate itself. With the very high tariff rates for weld rates the outlay on making good weld damage often exceeded that required for annual main engine maintenance. This applied particularly to vessels trading in ice or muddy waters. Modern coatings were available that solved this problem completely and also avoided the need for fitting anodes along the side of the hull. Such coatings were seldom, if ever offered by the shipbuilder except as an extra. Because their application was not planned into the shipbuilding sequence the cost of such an extra appeared, in the owners' view, to be extremely high when compared to the cost of the raw material.

Finally, as things were at present a shipbuilder had no alternative but to offer a well proven design at the lowest possible first cost if he was to sell any ships at all. Likewise the owner must operate well proven ships at minimum cost if he was to stay in business. Where perhaps there was some difference of view was that the owner was really concerned with reducing the total life cycle cost rather than keeping the first cost to a minimum.

MR. R. COATS F.I.Mar.E., said that the authors had taken an example of a regenerative industrial gas turbine driving electric generators and utilizing waste heat to produce steam for ships' services. This was a good and economical arrangement but did not appear to show up too well on Fig. 9, largely as a result, he suspected, of the large increase in ship cost attributed to it. As he could not see that extra cost being in the gas turbines he presumed it was largely in the electrical transmission side of the arrangement. But in certain types of ship this arrangement of having a power station producing electricity on the ship allowed the installation of the machinery on an upper deck with a reduced length of inlet and exhaust ducting. It also solved the reversing problem in a practical way.

He suggested that this regenerative cycle was not the optimum solution for the use of turbines for propulsion either for acquisition, installation or operation. He hoped he would be forgiven for returning to a hobby-horse he had been riding for a number of years. It had changed a little in size and appearance over the years, mainly in the direction of simplification and streamlining. He referred, of course, to the combined steam and gas turbine cycle, in which the main features were:

1) the gas turbine was the dominant partner and provided the major control features;
2) the gas turbine exhaust was ducted to a waste heat recovery boiler to generate steam in substantial quantities; this steam was supplied to a single cylinder steam turbine to provide about 40 per cent of the total power; the only feed heater in the system outside the boiler was a de-aerator; the remainder of the feed heating was done by recirculation of water within the boiler, part of which was mixed with incoming feed to attain the required temperature;
3) control of power was effected by fuel input to the gas turbine only, with a secondary control on variable inlet guide vanes at the compressor inlet; the steam turbine power followed the amount of steam supplied to it on the floating pressure system; gas turbine and steam turbine were rotationally linked, electrically in a turbo-electric system similar to the authors', or mechanically in an in-line arrangement driving a common alternator, or again mechanically in a geared drive arrangement.
4) the efficiency was high, reaching 39–40 per cent at the power levels of the authors' example; it was also less costly, because of the elimination of one gas turbine, of two regenerators and large diameter piping, and the substitution of a single waste heat boiler and steam turbine;
5) the system was simple, stable and controllable, and suitable for remote and mainly unattended operation.

He therefore challenged the authors' implications that the combined cycle was a complexity which was unattractive, and could say from established land practice with such machinery that the operation was much less onerous than with simple steam turbine machinery of similar power.

Where would the authors, therefore, see the economic analysis of this type of machinery fitting into Fig. 9?

One of the more exciting developments in the marine gas turbine world at the present time was the introduction of the reversing marine gas turbine. He had recently been privileged to watch this in operation on the test bed at full manoeuvring power, the load being absorbed by an electric generator of 9 megawatts, under fingertip control, and the performance was most impressive. There was a loss of internal efficiency due to windage of the astern blading when running ahead, but most of this was regained when exhaust heat recovery was used, and this was important.

He regarded this as the major prime mover for the future for mechanical drive, and in conjunction with a simple steam turbine in a combined cycle. With such an arrangement it would probably be better to use steam for driving the cargo pumps, and it would be completely new exercise to arrive at the correct line on Fig. 9. His guess was that it would show up as superior to all others because the mechanical drive would be less expensive than the electrical transmission.

A further relevant point was that the combined cycle had a relatively flat consumption curve retaining a good efficiency down to half power. This removed one of the disadvantages of the simple gas turbine arrangement.

Mr. E. A. Bridle M.I.Mar.E., said that when he first read the authors' comments on type testing and international standardization he thought they were referring only to auxiliary and ancillary equipment, but from what Dr. Milne had said it was clear that he was also talking about shore testing of the main propulsion machinery, for which a fairly major test establishment would be needed of the type which was so eagerly dismantled on the River Tyne not far from the authors' works a few years ago.

However, a problem which struck him about a type testing establishment like this was that it would be testing a number of different types of equipment by different manufacturers. Would they all be willing to submit their equipment for testing when the results of these tests might become freely available to their competitors? There appeared to be a commercial problem here.

With regard to the overall design process, he had wondered in reading the paper how much was conjecture, how much reflected the general opinion of shipowners and shipbuilders, and how much was what the authors' own company had in mind. He certainly agreed that the introduction of comprehensive design studies leading to detailed specifications was a highly commendable objective, but from experience in his own organization with this type of work for naval machinery installations, he knew that it was an extremely expensive exercise. Would the shipowner be willing to pay for this, even when a large class of similar vessels was envisaged?

Turning to steam turbines, he wondered why the authors suggested that the simple steam turbine cycle should be used for the higher powers and that the re-heat machinery should be restricted to medium powers. Was this because fuel cost was less important in the high powered container ship than in the lower power VLCC, as the authors suggested in the section on gas turbines a little later in the paper?

He was surprised that the authors suggested a two boiler installation for re-heat machinery. He would have thought that the problems of controlling re-heat boilers in parallel during manoeuvring conditions could be quite difficult.

On the question of gearing, a graphical presentation of the gearing limits, similar to that given for the propeller data, would have been useful, but would not the change-over from double to triple-reduction also be controlled by reduction ratios to some extent? Main shaft speeds of 60 rev/min, with turbine speeds of about 6000 rev/min, required a 100:1 reduction ratio, which would result in very large primary wheels in a double-reduction gearbox.

With regard to epicyclic secondary gears, he was intrigued to know what sort of primary gears the authors had in mind, with twin inputs from the turbines.

The high speed diesel engine data was tabulated but the authors had not made any further reference to it. Perhaps they could say something on that in their reply.

On gas turbines, the authors stated that with the aeroderivative type "shore based gas generator spares might even be necessary". He suggested that in the present state of development they were abosolutely essential.

Would the authors enlarge a little on their suggestion that the aero and industrial derivatives might converge? He was not sure what they meant. Could it be that the life of the derivative aero gas generator would get longer, and that perhaps provision would be made for a deliberate planned replacement of a shorter life industrial gas generator once or twice in the life of the ship?

With regard to combined gas/steam turbine cycles, the paper prompted the question, "When is a combined cycle not a combined cycle?" The proposed gas turbine installation had three waste heat boilers, a steam accumulator, a packaged boiler, two gas turbo-generators, a steam turbo-generator and a diesel generator. Was this really much less complex than the combined cycle dismissed by the authors earlier in the paper?

With regard to nuclear power, apart from refuelling arrangements one of the big drawbacks so far had been the lack of international agreement on safety aspects and access to ports. Finally had the differential capital cost of nuclear and conventional plant, to the authors' knowledge, increased faster than the differential cost between nuclear and fossil fuels?

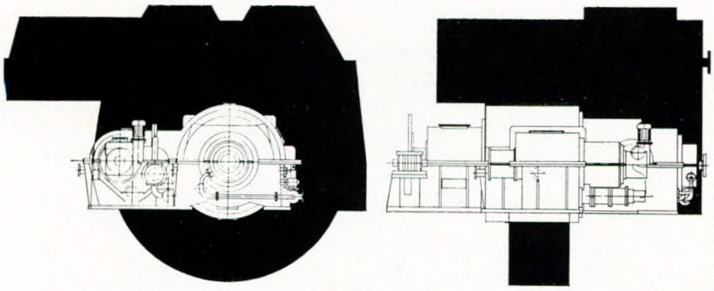

FIG. 11—*Comparison between epicyclic gear under construction and equivalent parallel shaft gear*

MR. D. E. YATES, M.I.Mar.E., said that the paper had indicated that epicyclic gears would be used increasingly for steam turbine, gas turbine and diesel propulsion plant because of advantages which could result from both the cost and installation points of view.

It was worth-while to give weight to the authors' arguments by showing a typical direct driven gas turbine installation now under construction compared with a conventional double-reduction tandem articulated gear (see Fig. 11). In the case in point an alternator/motor drive was included and manoeuvring was carried out by means of a c.p. propeller.

There were a number of problems in the manufacture of large epicyclic gears, not the least of which was the cutting of large internal gears to the required accuracy. In this respect Fig. 12 showed a gear for 26 000 kW with a propeller speed of 140 rev/min and an annulus diameter of about 2 m. Fig. 13 showed an experimental annulus of more than 2·5 m diameter being successfully gear cut.

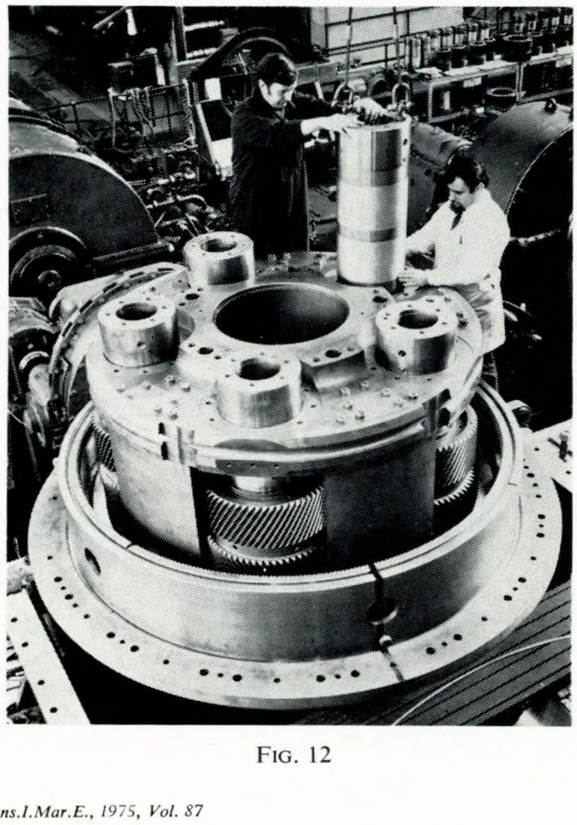

FIG. 12

MR. E. W. BELL, M.I.Mar.E., said that to one involved in promoting heavy duty, long life, gas turbines for marine propulsion it was most gratifying and encouraging to hear the views on this type of engine expressed by the authors.

In reviewing this rather complex subject of comparing prime mover types he complimented the authors on their thoroughness and fairness in considering the various parameters.

The gas turbine/electric propulsion system, on a first cost, carcase price basis, did not show to advantage, but by designing the ship/machinery requirements around the particular prime mover a different picture emerged.

With reference to Fig. 9, the difference between the prime movers was not so wide, and a shipowner would no doubt have a lot of weighting up to do before making a decision to select his machinery.

There were several factors, however, to support the choice of heavy duty gas turbines in the application under consideration. He would limit his remarks to only one—the question of reduction in crew requirement. The effect was shown up clearly in the amended data produced by the authors. Reduced manning was achieved through acceptance by classification societies, particularly in the United States, of the design philosophy with regard to ease of control and minimal operational maintenance.

FIG. 13

The gas turbine under review was of the General Electric U.S.A. design with its own General Electric designed control, monitoring and supervisory system. This was an inherent feature of this equipment, and the solid state electronics and hydraulic actuating components incorporated within the gas turbine module were specifically designed and integrated into a "tuned" system, resulting in reliable, trouble-free, remote operation. This philosophy had resulted in a high reliability factor—statistically 99·5 per cent over 45 million operating hours on industrial machines, on which the marine units were based.

COMMANDER J. P. W. MIDDLETON, M.I.Mar.E., said that as a submarine engineer the paper lay somewhat outside—or perhaps above—his habitual environment. However, he greatly appreciated the section headed "Trends in Machinery Installation Design", which was a model summary of imaginative but realistic design policy.

There was one point which he believed required correction. That was where the authors referred to the use of operating instrumentation data to derive trends and hence reduce the maintenance load. The aim was absolutely right but the relatively coarse instrumentation used for operating was not really appropriate to that required to identify incipient defects. For instance, a fraction of a bar drop on a feed pump discharge pressure of, say, 60 bar might indicate the need for impeller or sealing ring replacement but would hardly be measurable on an instrument looking at the full output pressure range from 0 to full power.

It was also essential to design machinery from the outset for non-dismantling static and dynamic inspection, and to provide special test equipment and procedures. But it was certainly worth it.

With regard to Dr. Milne's remarks about the degree of training to support maritime nuclear plants, he could only endorse Dr. Milne's concern, particularly in view of the transitory nature of the operators, which had been mentioned. This would be a matter of critical importance when the time came to re-assess the possibilities of mercantile nuclear plant.

Mr. M. Cochet thanked the authors for giving such detailed figures in their forecast of future developments in machinery installations.

It was clear from the paper that the diesel engine was a better proposition for propulsion machinery, due basically to its low specific fuel consumption. However, it seemed that the advantages of medium speed engines were somewhat neglected in this comparison between different propulsion schemes.

With regard to heavy fuel, the authors stated that if only lower grades of fuel oil were available, the gas turbine and medium speed diesel could not be considered. This was quite wrong as far as medium speed diesels were concerned.

It must be known that medium speed engines with water-cooled exhaust valves could burn residual fuel with viscosities up to 3500–4000 seconds Redwood 1 at 100°F, with a sulphur content up to four per cent and vanadium up to 400 ppm.

In such circumstances it was, of course, necessary to use an alkaline lubricating oil with a total base number of about 40. This also applied with low speed engines where the cylinder oil was even more highly basic, probably TBN 70.

Maintenance of such exhaust valves could be done at intervals of 6000 hours without dismantling the cylinder head.

On the question of different installations with reduction gear, Mr. Cochet said that by using reduction gear with medium speed engines there were many advantages. The first was choice of propeller speed. The authors had developed all possibilities offered to naval architects if they could choose the number of propellers and the exact speed of each.

The second was the facility to drive alternators by power take-off, thus reducing the requirement for continuously running auxiliary generating sets. This advantage was mainly important when the electrical balance of the ship was high, as on reefers or product tankers.

Thirdly, new, powerful medium speed engines were now close to developing 22 000 kW with one unit of 18 cylinders in vee form.

It was now possible to have this high output with one medium speed engine only, but the advantage of the twin engine installation could be kept with a two input gear with two in-line medium speed engines of large bore to reduce the number of cylinders if it was preferred.

Fourthly, due to weight and size, it was not necessary to dismantle medium speed engines to install them on board. Thus propulsion machinery with two medium speed engines and reduction gear was more quickly installed and at a lower cost than one low speed engine which had to be dismantled after running in the workshop and then refitted on board.

This advantage reduced the first cost of a new ship and sometimes the delivery time.

With regard to two-stage turbocharging, Mr. Cochet said that this development to increase specific output of the medium speed engine was being tested by many engine designers.

Contrary to what the authors said, it was more convenient to adapt a medium speed diesel engine to two-stage turbocharging than a low speed engine.

These remarks were confined immediately to turbo-blowers to avoid any long discussion on other parts.

In one design the high pressure turbo-blowers would be disposed in the normal position on an engine, but the LP turbo-blower, with its intercooler, could be installed anywhere in the engine room. But to reduce manifolds and pipework it might be convenient to install this LP group on top of the reduction gear.

The increasing of air flow, not only in regard to the increasing power but also by the amount used to cool the piston head, made it necessary to use a larger LP turbo-blower than standard.

But if large turbo-blowers of the size normally used on low speed engines were sufficient for LP turbocharging in a two-stage turbo-charged medium speed engine, it seemed that designers of turbo-blowers would be obliged to design new, larger units for two-stage turbocharging of low speed engines.

Moreover, it did not appear, due to the number of service hours in a year, that propulsion machinery for merchant ships would be the first application of two-stage turbocharging. Warships on the one hand and power plants on the other would be the first applications, and in this market the low speed engine was not so prominent as the medium speed engine.

So medium speed engines with two-stage turbocharging would be able to accumulate more experience in service in naval installations or land applications before being applied to merchant ship propulsion.

Concerning machinery for VLCC, Mr. Cochet said that the authors had made comparisons between steam turbine, gas turbine and low speed diesel engines for VLCC propulsion.

It would be interesting to compare also a twin engined installation of the third generation of medium speed engines, for example 2 × 15 000 kW. Since the increase in the cost of fuel, many shipowners and shipyards had studied the possibility of replacing the steam turbine installation by medium speed diesel engines, at the same time maintaining the same size of engine room and the same propeller speed, which would be impossible with a low speed engine; in fact, it was a serious difficulty in tanker building which had temporarily held up the development of this application.

Finally, the better consumption of this powerful medium speed engine, something like 4–6·75g/kW less than the low speed diesel engine, was a very attractive feature.

Did the authors feel that all these advantages brought about by the availability of the 1100 kW/cylinder medium speed diesel engine could now be considered strong competition for the low speed engine for marine propulsion?

Were there not specific hopes that the growth of this new, powerful engine would produce a similar rate of growth to that shown in Fig. 5?

Mr. J. Cliffe questioned the statement about the gas turbine being able to accept the same types of fuel as the diesel and steam turbine. He very much doubted that it was possible without considerable derating. Certainly it would be unlikely to tolerate 1500 second class fuel with normal levels of vanadium of 100 ppm or more. A very tight control of vanadium and sodium levels was necessary. Vanadium levels as low as 1 or 2 ppm was really the limit without fuel treatment, and anything in a higher region would create severe problems unless low temperature operation was adopted. Fuel treatment could be employed, such as magnesium dosing at three times the vanadium content, but this tended to put up the cost and fouling rate and it was then more advantageous to burn a lighter fuel. Sodium levels had to be down to about 0·5 ppm, which meant that aerial contamination could occur in tankage.

With regard to the combined cycle, he tended to agree that this did not seem likely to be adopted. Based on land experience, this was partly because the capital cost was likely to be higher than alternative types of plant and also because the type of gas turbine which appeared to be most advantageous for a combined cycle was a low pressure ratio and relatively inefficient one with a high exhaust temperature—this latter was against the trend of development of gas turbines.

He agreed that the industrial and aero type gas turbines would tend to merge, and this was already happening. The aero-engine had been derated, with lower temperatures to give longer life. Twenty thousand hours' life was now possible with an aero-turbine and, conversely, the industrial type machine was going up in temperature. They might well converge.

With regard to steam turbines, he would regard it as a retrograde step to introduce the reheat steam cycle, basing this on the disappointing experience of the reliability aspect of these cycles. If a change in steam conditions were thought necessary, a higher pressure non-reheat cycle would be worth looking at. This might well become possible in view of the recent developments in nuclear steam turbines which were tending to reject reheat cycles, and a higher level of moisture at the back end of the turbine. Blading erosion was not such a problem as it used to be.

Turning to diesel machinery, he felt that the medium speed engine had not received enough prominence in the paper and that the high speed type engine had barely been mentioned. Considerable development could occur here in the future. The value of bmep for the 1000 rev/min engine might well go higher than the figure quoted, especially with two-stage turbocharging. As a previous speaker had mentioned, these medium speed engines now had the ability to burn very heavy grades of fuel and in practice there did not seem to be much between them and the low speed engine in this respect. There might be a tendency here for medium and high speed engines to converge somewhere; possibly a 600–750 rev/min engine might emerge.

MR. G. VICTORY, F.I.Mar.E., said that this was a paper on development. Obviously there were great economic considerations involved in any development, but it would appear that there was not much economy in safety, judging by the section concerning this in the paper. However, he was grateful to the authors for introducing certain items, with all of which he agreed, showing that sometimes what appeared to be economy could be false economy. Some of the features mentioned would require a little more money but would certainly be economical in the long run in terms of casualties. It was surprising that the authors referred to a "get-home" capability when both the turbine installation examples given had twin main boilers. Certainly he would like to see twin main boilers available.

There was one other safety aspect of tankers which he thought worth bringing up, particularly as the meeting was being held in the RINA building. This was that the tanker had a wonderful survival capacity after collision or explosion damage, providing it was hit anywhere except the engine room. Also, there was enough water going round the engine room to ensure that if one of the major pipes or circulating systems were breached the machinery spaces would flood rapidly. In most cases, because of the large volume flooded at the after end, the ship would subside and sink by the stern. He wondered whether such losses were necessary? It would be possible to sub-divide the engine room so that the ship could survive with one or more parts of the engine room flooded. For example, in twin-screw, twin-engine machinery this might be done by a centre line bulkhead with certain side spaces used as tanks to prevent too great a list developing. In other cases certain items of the machinery could be bulkheaded off into special spaces, so reducing the floodable volume. It would then be possible to provide individual extinguishing systems (say Halon 1202 or 1401) to such spaces, whilst in respect of noise it would be very useful to have some of the engines or machinery in different compartments to facilitate at-sea maintenance. If all these factors were put together it might be possible to go along to the insurance interests and get some reduction of premium. He had his doubts about this because they were very loth to introduce any differential for the provision of inert gas. But it might be worth trying, for if more interest was shown by the insurance interests in what they were insuring, it could produce effective results in regard to safety measures.

With regard to nuclear power, it could be shown that in certain types of ship this would be economical as compared with oil at the present price. There were other problems such as insurance and acceptance in foreign ports, but he would not put quite the same emphasis on training. When comparing the complexity of the modern ship with those even of a decade ago, it showed that it was, he thought, possible to train people to operate and accept responsibility for new developments, including nuclear installations. They might need to have money spent on their training and to be paid a lot of money, but they could do it. The question of acceptance into ports internationally, raised by one of the other speakers, would need to be cleared up if nuclear ships were to be made more viable in the future.

Correspondence

MR. G. C. VOLCY, M.Sc., F.I.Mar.E., wrote that he had read with much interest the authors' considerations concerning the trends in machinery installation design, but regretted not having found any mention of a very advanced propeller arrangement; namely, overlapping propellers, in the comparisons between steam turbine and gearing driven plants.

Experimental studies executed in several competent towing tanks had shown that the propulsive efficiency of this propeller arrangement, compared to the conventional twin-screw arrangement was 12 to 15 per cent better; the economical advantage being evident.

He agreed with the authors' opinion that tandem contra-rotating propellers should not be considered as a likely development for future big ships until a satisfactory outrigger bearing was available. Another handicap of the contra-rotating propeller arrangement might be the problem of gearing affected by hull deformation, due to the flexibility of thrust bearings. But this was not the case for the overlapping propeller arrangement, which was relatively simple and conventional for naval architects and marine engineers. In Fig. 14 such an arrangement was predicted for a large LNG carrier.

For such an installation serious problems might arise concerning cavitation and vibrations. The authors referred to the latter by drawing attention to the fact that particular care should be taken regarding vibration characteristics in big tankers, and that a rather sophisticated study of free and forced vibration behaviour of such an installation had been executed. During this study particular attention had been paid to the behaviour of the stern gear, for which a particularly careful model of the bossing steelwork had been made. Fig. 15 showed such a model.

Fig. 16 showed two modes of free vibrations of the bossings and corresponding hull steel work.

The hydrodynamic excitation being determined experimentally by the Wageningen Towing Tank, it would also be possible to calculate the response in forced vibrations of the assembly constituted by both propellers and shaftings, together with their bossings connected to the neighbouring steelwork of the hull girder. The results were shown in Fig. 17. For more details see Ref. 8.

From these statements the conclusion could be drawn that naval architects and marine engine builders were now in possession of sufficient technical tools to make it possible to adopt the most sophisticated installations.

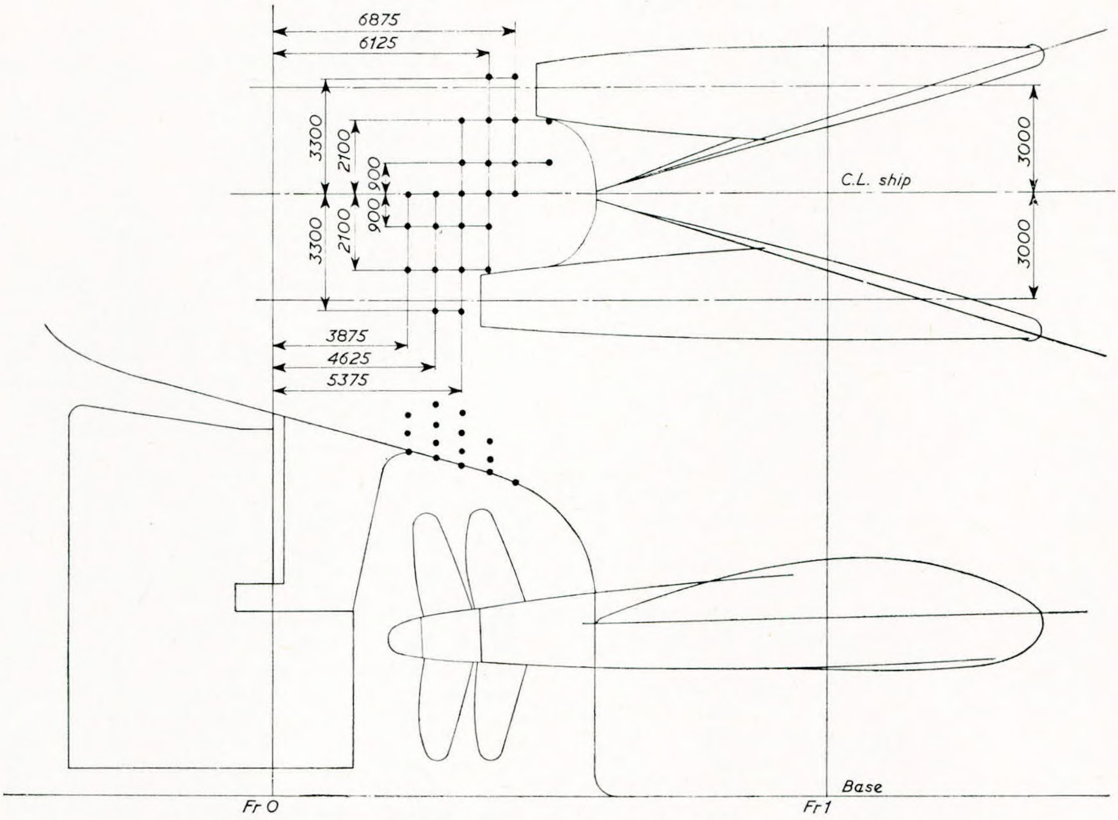

FIG. 14—*Propeller arrangement and positioning of pressure recorders*

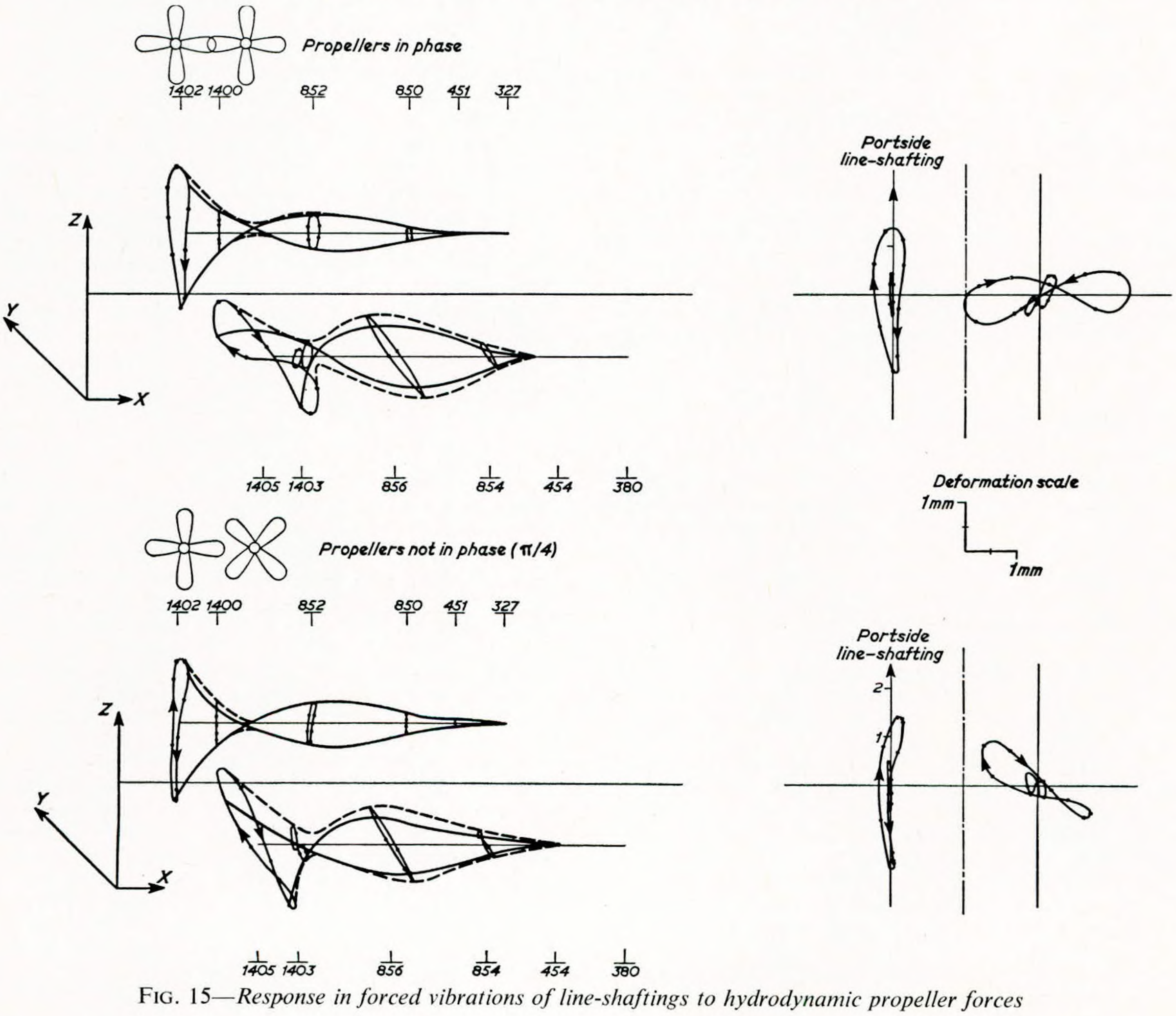

FIG. 15—*Response in forced vibrations of line-shaftings to hydrodynamic propeller forces*

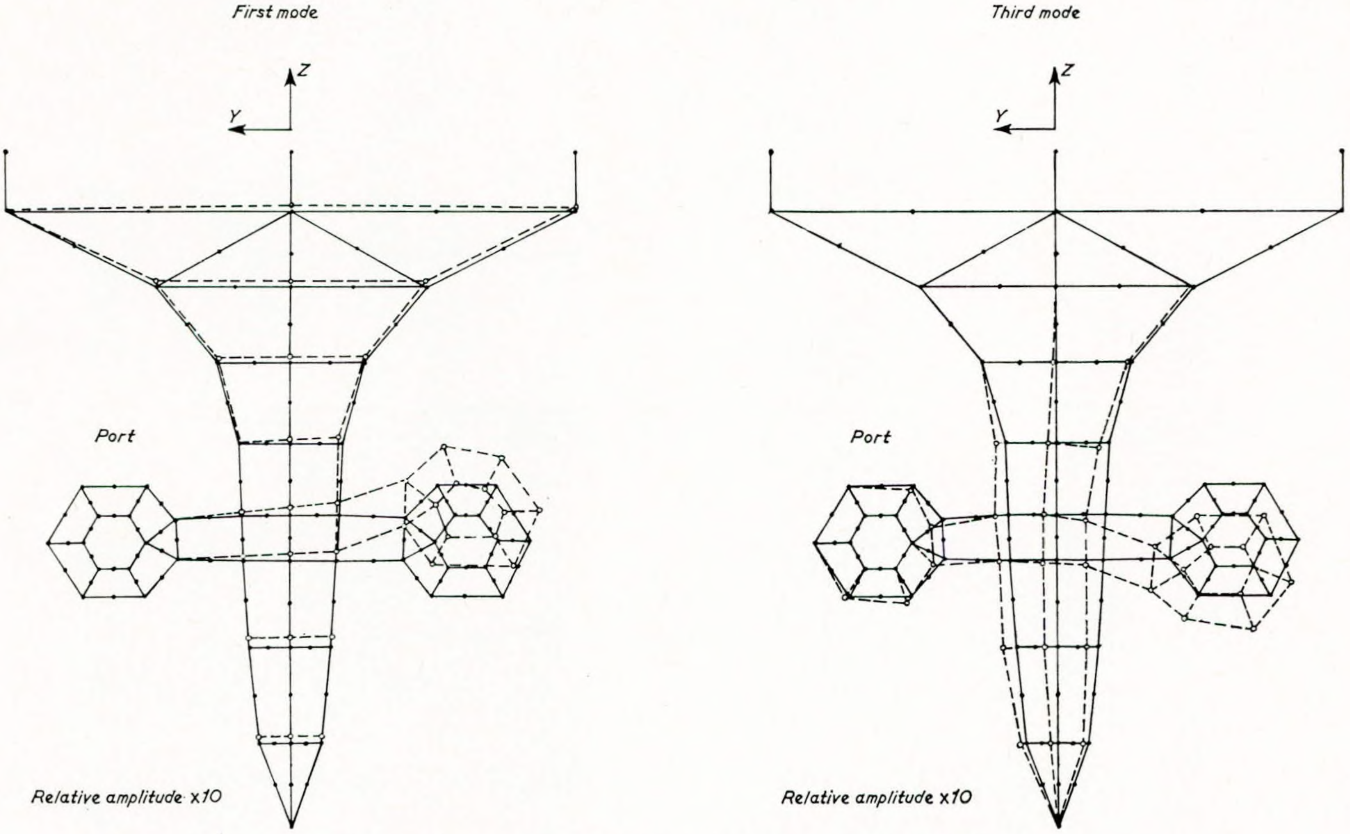

FIG. 16—*Mode of bossings corresponding to free vibrations of shafting*

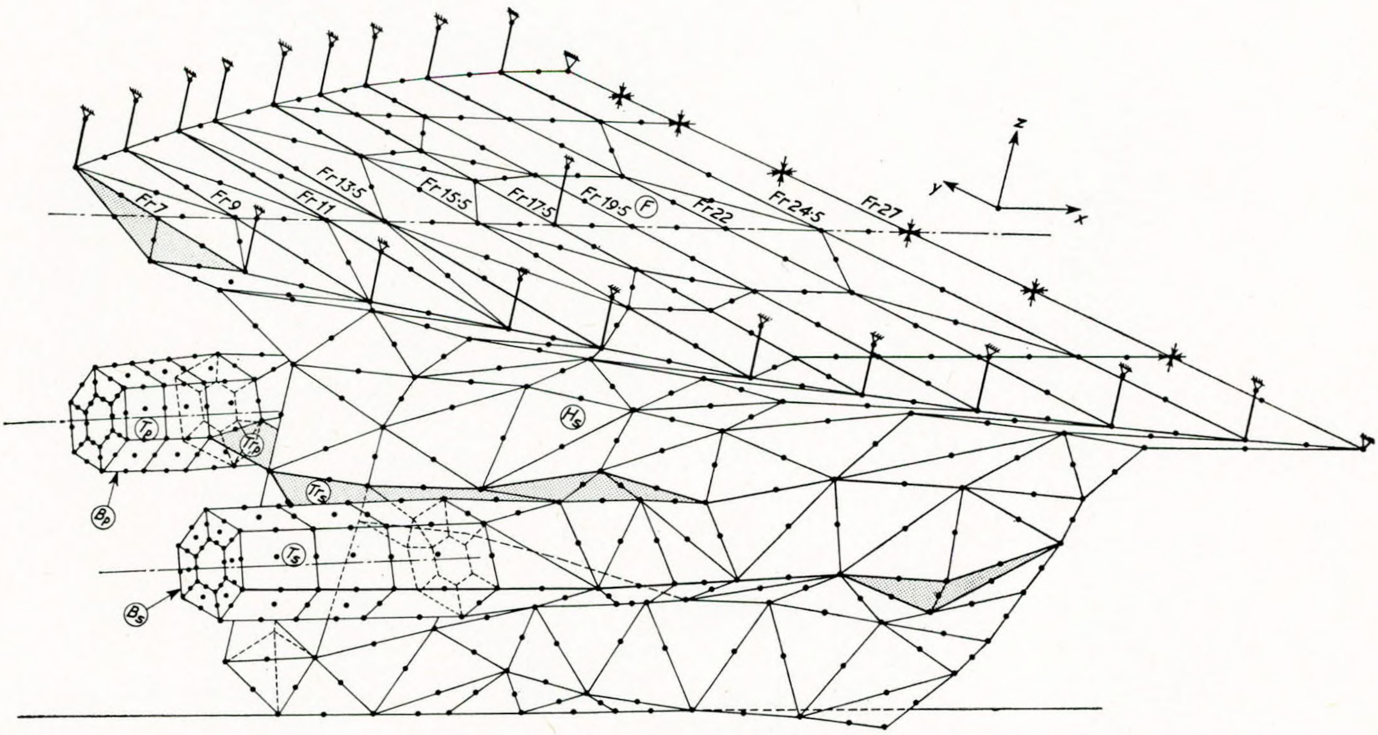

FIG. 17—*Elasto-dynamic model of bossings steel-work*

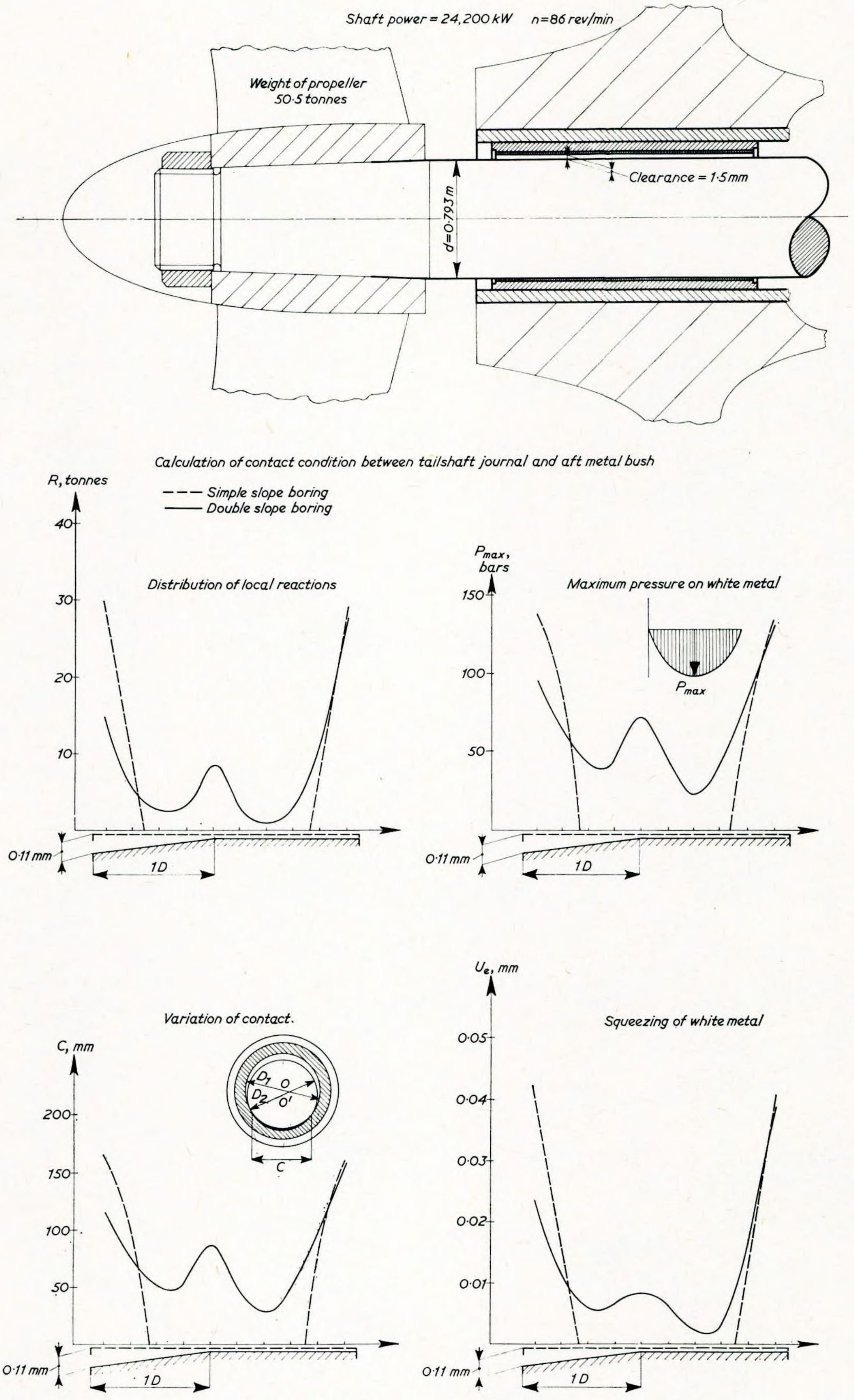

FIG. 18—*270 000 dwt turbine tanker*

In this respect, he also agreed with the authors that the actual trend in shipbuilding was towards a period of precision. Fortunately they were well prepared for such a challenge. But, as the authors knew, some serious problems arose on VLCC concerning the true behaviour of white metal stern bushes. In fact, due, on the one hand, to the incompatibility of steelwork flexibility and stiffness of shafting, and on the other hand, to the increase of the importance of hydrodynamic excitations, especially thrust and its eccentricity, particular attention should be paid to the contact conditions between the tail shaft journal and the aft support of the tail shaft.

Mr. Volcy referred to the results of a recent study, executed by the Special Study and Research Section of Bureau Veritas Marine Departments, concerning the real pressure distribution between tail shaft and aft bush. The specific pressures existing on the aft stern tube far exceeded the values mentioned by the authors as being equal to 6·6 bar (657MN/m^2), which did not correspond at all to real contact conditions. If account was taken of the real alignment condition and flexibility of whitemetal, the real local pressure on whitemetal was 147 bar (14·7MN/m^2). Fig. 18 showed some results of calculations for a 270 000 dwt tanker where the mentioned values could be shown. To lower these values it was necessary to adopt a new approach, achieving contact between journal and aft bush as uniformly as possible. For this ship, the Bureau Veritas approach had been adopted, consisting of slope boring a stern bush accompanied by double sloping the aft extremity of whitemetal, as also shown in the same figure. By applying such a technique, this maximum pressure was halved and the ships were running well, confirming the validity of the solution adopted by the Society many years ago.

Further study concerning the influence of the oil film on the behaviour of the line shafting would also be more thoroughly investigated, especially for limit lubrication conditions. Such a study was under way and as soon as it was finished the contributor would not hesitate to put the results at the disposal of the shipping and shipbuilding community.

REFERENCE

8) Restad, W., Volcy, G. C., Garbier, H. and Masson, J. C., 1973. "Investigation on Free and Forced Vibrations of an LNG Tanker with Overlapping Propeller Arrangement". SNAME.

Mr. P. B. Owen wrote that the paper presented a forecast of what the future could hold in store for the marine industry. Inevitably, a paper such as this ought to attract constructive criticism, because the future was never easy to predict and there were many sides to the arguments which had to be resolved. This contribution was, hopefully, constructive criticism on some areas of the information presented in the paper. His basic argument was that despite fuel price influences, lower optimum speeds, etc., the case for the slow speed diesel was not as dramatic as the authors had inferred; in fact his own prediction was that once the dust had settled and negotiations for new ship orders started, the steam turbine would still be used for the vast majority of the higher horsepower installations.

All steamships contracted to burn bunkers with a viscosity of 3500 seconds Redwood I; to get an oil of viscosity 1500 seconds Redwood I, as used by most motor ships, required a blend of approximately 91 per cent bunkers with nine per cent diluent. Taking the current relative costs of the bunkers and the diluent, this gave an extra cost per tonne for the lower viscosity fuel of about six per cent. This differed somewhat from the four per cent differential suggested by the authors. Furthermore, all steamships could burn fuel of up to 4200 seconds Redwood I; such fuel showed very little deterioration in quality, but showed a nine per cent cost saving compared to the 1500 second fuel. If one assumed the normal 3500 second fuel to cost £35/t, then the 1500 second fuel would cost £37/t and the 4200 second fuel £34/t. Using the authors' graphs in Fig. 9, even without further question of the basis of the comparison, gave a required freight rate of about £5·10/t for both the diesel and the turbine.

On the subject of heat cycles for turbine installations, the authors were correct in suggesting that there was a general return to twin-boiler installations. However, there seemed little logical reason for this trend, the existing single boiler installations, with an auxiliary boiler for peak load, tank cleaning and "get you home" service, having given excellent reliable service. It was true there were a few teething problems, but not of sufficient magnitude to invalidate the concept. The twin-boiler reheat system proposed by the authors would be particularly complicated and one could rightly question the reliability of such a plant. It would involve a separately fired reheat boiler; the existing designs for such systems had very complex combustion control systems. In contrast, a single boiler reheat system was relatively simple. In his opinion future steam plants would have single boiler reheat turbine installations. With initial steam conditions in the region of 100 bar/510°C, a fuel consumption of 250 g/kW h was easily attainable.

The final point Mr. Owen wished to make concerned the days in service the authors had used in the various options in their analysis. They quoted 349 days in service for the steamship and 347 days for the diesel. These figures were typical of those seen repeatedly quoted in the technical press. However, he doubted whether they were accurate and they certainly did not reflect his own experiences. Very often the maintenance problems of the motor ship were not truly reflected in the stated figures because of "illegal" overhauls performed in port when, strictly speaking, immobilization of the main engine was not permitted. Mr. Owen suggested that a well maintained, correctly run motor ship could be out of service for up to ten days per year more than the steam alternative, and he was convinced that the two days differential quoted by the authors was suspect.

To make his point, Table V was included, a very simple recalculation of the authors' economic comparison. The main points of difference were:

1) only the 23 530 kW turbine and diesels are compared;
2) the turbine ship has been changed to a reheat installation with £1 000 000 extra capital costs;
3) the fuel consumption of the diesel has been reduced somewhat as it is assumed a waste heat recovery system would be installed;
4) the capital element of the annual charge has been treated very simply as a straight mortgage at 12 per cent over 20 years;
5) the author's maintenance figures have been used, but the steam installation increased by 5 per cent to allow for extra maintenance of the reheat installation;
6) the days in service have been amended to 350 steam, 345 diesel.

Table V

	Reheat turbine	Motor ship
Power, kW	23 530	23 530
Average speed	15·42	15·14
Cargo, t	281 380	279 260
Cost, £m	25·7	24·7
Fuel rate, g/kW h	250	216
Fuel consumption at sea, t/day	141	134
Fuel cost, £/t	34	37
Voyage distance, miles	22 400	22 400
Days in service	350	345
Voyages/annum	5·27	5·10
Costs/annum, £:		
Maintenance	277 000	327 000
Crew	186 000	186 000
Fixed	640 000	640 000
Port	19 000	19 000
Capital	3 440 000	3 307 000
Fuel	1 526 700	1 558 800
Total	6 088 700	6 037 800
Required freight rate, £/t	4·11	4·24

Because of the simpler financial approach and the zero escalation allowance, the analysis gave required freight rates below those of the authors, but it did show the reheat turbine to be more attractive than the diesel.

The events of the past year had done little to help resolve the old steam/diesel arguments. The question in the future would be "which installation involves the least technical risk—the diesel or the reheat turbine?" On paper they still appeared to be far more equally matched than the authors would admit.

Mr. E. F. Kirton, F.I.Mar.E., wrote that he would be grateful if the authors would expand their views, only briefly mentioned in the paper, regarding the need and extent to which formal quality assurance procedures were, or would be required for merchant ship engineering systems.

It was increasingly shown, in all environments of growing complexity, that a lack of attention to detail could have expensive, if not disastrous, consequences and there was evidence to indicate that some shipbuilders had not raised the standard of their testing, commissioning and system verification procedures to match the requirements of the complex and sophisticated marine installation. Arguably, moreover, the shipbuilding industry as a whole was behind other industries, of comparable technological content and produced product value, in terms of the effort devoted to determining the functional acceptability of the final product.

The need for compromise, between the attainment of quality perfection and blind confidence that unproven systems would perform satisfactorily in service, was clear, but determining the right level of quality assurance appeared to be difficult. What were the authors' views, preferably in quantitative terms, regarding the required level of effort? Also, what were their views on the creation of quality assurance departments, and the procedures and terms of reference to which they should work?

Much had been published regarding the nuisance and cost of maintaining sea water cooling systems and it would seem inevitable that there would be a growing acceptance of any principle which minimized or eliminated the use of sea water in the machinery spaces. What, therefore, were the authors' views on the use, in motorships, of a single, sea water cooled, central cooling system for total machinery systems, and on the prospects for shell or keel cooling systems, limited perhaps, to auxiliary cooling systems?

Mr. H. C. K. Spears wrote that it was apparent that much prior effort had been done as background for the studies in the paper and that the authors had had to choose among a number of the supporting investigations in order that the paper be of a manageable size. It was to be regretted that space must have precluded the additional information, as in a number of cases it was not possible independently to check the presented results. A few examples would suffice.

Fig. 9 would indicate that for a VLCC of approximately 26 000 kW, the diesel gave the lowest required freight rate at essentially any fuel cost. However, this was completely at variance with his experience and the world's purchasing habits, where the great majority of those ships were steam propelled.

In a discussion of future developments, it would appear only reasonable to use a modern steam plant for comparison with the other prime movers. At that power, more than fifteen steamships had been successfully at sea for at least six years, with all-purpose fuel consumption of about 245 g/kW using reheat cycles. Further, the days in service for gas turbines on residual fuel did not agree well with actual achieved experience in base load electrical utility service when compared with steam.

The fuel consumptions for the slow speed diesel presumably included lubricating oil, yet all-purpose fuel rates were only four per cent higher than the engine specific fuel consumption, which was surely optimistic. If the assumption was that a full suit of heat recovery steam generators was fitted to the diesel ship crude carrier, then the equality of ship price was questioned, as normally with that arrangement the steamship was less expensive.

It was suggested that, in these days of ever poorer fuel quality, some mention should be made of the steamship's ability to burn all fuels, including the 5½ sulphur boscan, with machinery plant maintenance costs about one quarter of that of competing prime movers. It was not his intention to claim steam superior for all ships, however crude carriers and container ships in the higher powers could economically have steam propulsion and could bunker the poor fuels presently available.

Dr. I. L. Buxton, B.Sc., wrote that the quadrupling of oil fuel prices in less than two years affected not only the direct comparison of alternative machinery shown in Table IV and Fig. 9, but also changed the design requirements. Such a change in fuel prices had the effect of reducing the optimal speed of a ship by around 10–20 per cent, so that installed powers might be up to 50 per cent of previous values, if the increase was regarded as permanent. The "natural choice" of machinery for particular ship types which the authors mentioned could be expected to alter somewhat. He would expect, therefore, the medium speed diesel to challenge the slow speed diesel more strongly in the smaller ships, and the slow speed diesel to challenge the steam turbine in the larger ships. Of course, the repercussions on the oil trade generally had also led to the current slump in demand for new tankers, which might well persist for a number of years.

The recent orders for container ships to service the South African and New Zealand trades suggested that something along the above lines was already happening. A few years ago, ships of these sizes (1800–2500 t.e.u.) would have had twin-screw steam turbine machinery of about 55–60MW to give speeds of 24–26 kn. In fact, the ships would be fitted with twin-screw slow speed diesels of about 38MW to give speeds of 21–23 kn.

The outlook for the steam turbine, even reheat designs, therefore looked bleak if one accepted both the lack of tanker demand and the results of Fig 9. Although he agreed that the industrial heavy duty gas turbine was more attractive for merchant ship propulsion than the aircraft derivative—and *vice versa* for naval vessels—and that the machine had many attractive technical characteristics, its fuel cost and first cost penalties would take a lot of overcoming. Applications up to 1985 were much more likely to be in special situations, where the machine's advantages could be fully exploited.

Certainly within the authors' time horizon, nuclear propelled merchant ships would be very few. If, however, oil fuel prices continued to rise rapidly in real terms as the world's reserves were diminished, the 1990s could be the period of take-off for nuclear power in high powered ships, but lower powered ships would continue to be largely oil fuelled.

As the authors had pointed out, developments leading to higher propulsive efficiency, like slower turning and ducted propellers, could be expected to make further progress. Maintenance of designed performance of ships in service would become a higher priority, both of hull and machinery. Better coatings could be expected to recover some of the usual drop in service speed from the new condition, now that ships were likely to be designed for slightly lower speeds than hitherto.

The authors' conclusion that more effort would be devoted to more detailed investigations at the design stage could only be applauded. Potential production problems were more likely to be highlighted before metal was cut, while a better overall solution would emerge from a fuller consideration of all the possible alternative designs. There was something to learn from the aircraft industry here, including better co-operation with the customer in defining his requirements.

It was encouraging to see the authors using engineering economics in their primary role: that of evaluating alternative designs. He was a little surprised that the lower powered versions of the slow speed diesel and steam turbine designs did not show to better advantage at the fuel prices assumed. Possibly the speeds of the higher powered ships were a little on the generous side (power proportional to speed to the 2·5 power rather than the normal 3 or more). Some slight increases in upkeep costs could be attributed to the higher powered alternatives, which might also have slightly higher insurance costs in view of their greater first costs.

While all the existing machinery types would continue to be seen at sea for many years to come, there were still plenty of challenges to the marine engineer in adapting to the new era of high energy costs that had been entered.

Authors' Reply

In reply to Mr. Kameen, the authors confirmed that in some ships built by their company the waste heat system was left out. The primary reason was the feeling the owner had that it was beyond the capability of the operating staff that he had available. No doubt a considerable training effort was put in, but the main problem was that of turnover. People were not in ships long enough to become familiar with them and to operate them. This was illustrated in the big tanker area, and had been raised in discussion with owners to whom such vessels had been delivered. The availability of these ships had been a lot less than expected, and one of the primary reasons was that they had not been operated in the way the designer intended. Often people, including the authors and the shipowners concerned, had designed outside the capability of the operator.

With regard to reducing the percentage of power taken from a plant, what people claimed a machine would do and what it would actually do were often different things. Most operators had come to the conclusion that if someone said that a diesel machine would run at a certain power continuously, at least 15 per cent should be taken off that in order to ensure continuous economic operation. It was possible to operate at the higher level, but the consequences on the maintenance costs would very quickly be evident. What the authors were suggesting was that, looking at the projected increase of power available, it would only be sensible to come down even further. As the power available from certain types of machinery might double in ten years, it would not be unreasonable to come down to 20 per cent of the power that the machine was claimed to be capable of producing.

When the authors mentioned reductions in the number of design teams available, this did not necessarily imply a greater degree of standardization; in fact, the point really was that the design of the types of ship now being put into service had become fairly specialized and it was not sufficient to produce a specification and buy equipment straight from that specification in the hope that when it was all put together it would work. It required a more fundamental design effort than had been available in the past.

With regard to Mr. Butler's remarks, in a lot of shipyards, now, there were facilities capable of lifting whole engines in. The authors' company tried to install the engine before the launch. This fitted in better with the construction of the vessel itself and also with the concept of pre-outfitting.

The grades of fuel mentioned in the paper and considered when looking at the various types of machinery were more the average grades, with no extremes. When competing designers started discussing machinery, they tended to look at the extremes, particularly if they suited the type of machinery advocated. The authors were trying to look at the type of fuel that people in general used, rather than going to extremes.

The twin-screw ships certainly were possible, but they were obviously more expensive and also there was a lower propulsive efficiency. To take the availability figures from engines or machinery which appeared in the first place to be suspect and then project those into a twin-screw installation would perhaps not give a very fair comparison between a single screw and a twin-screw approach. The authors did not have the basic data necessary to extend Fig. 6 to twin and triple-screw arrangements.

With regard to two-stage turbocharging, the reason it was suggested that this would be confined to the slow speed diesel was cost. It was felt that the relative cost of applying this to a slow speed machine would not be too much of a handicap, whereas when one began to apply this approach to smaller types of machine it could be prohibitive.

With regard to the question of not needing it at all, the authors were projecting much higher ratings than were shown on the graph used by Mr. Butler, where it would be necessary to consider the use of two-stage turbocharging.

With regard to noise requirements, this was rather a difficult question, but in fact what the medical people considered was required was not actually available, and this was one of the practical problems at the moment. The authors agreed that 90 dB would be difficult to achieve, in medical terms it would allow eight hours continuous exposure without permanent damage. It was obviously an area that had to be looked at in terms of design, so that people could design within the limits. There would ultimately be a statutory requirement and this was why it was mentioned in the paper. The authors' view at the moment, supported by collected evidence, was that what the medical authorities wanted was absolutely unattainable unless one approached it in particular ways. There was a word of caution about this as it was an area which, as powers increased, would require increasing attention.

Mr. Butler seemed to have chosen all the points favouring a particular design. It was certainly a good idea to start with an engine that was well balanced. Very often there was the choice of a basic engine which was badly balanced, with the optional extra of some balancing equipment which gave a result somewhere near what was wanted in the first place.

In reply to Mr. Bowers, the authors had not meant to neglect the medium speed diesel. It had been given its due emphasis when looking at the bulk carrier and the products tanker demand and was increasing its share of the market in some of these types. It was not included in the particular economic assessment made in the paper, because the authors wanted to take the opportunity to look at the gas turbine and compare it with the two types of machinery that were the major types used at this time.

There was no doubt, despite what had been said by a number of speakers, that there was a reluctance on the part of some shipowners to believe that the medium speed diesel was capable of burning the poorer grades of fuel, and the authors had experience of owners who had refused to believe this and had chosen medium speed diesels only when the grades of fuel were suitable in their opinion for use with that type of machinery. The authors were reporting from their experience and believed this was reflected across the board in the ships on order. The availability obviously would be increased with having twin-screw installations.

The authors noted the comments on the future development of auxiliaries. The problem was that there was a vast difference, unfortunately, between what could be done commercially; this included shipowners as well as shipbuilders, and what their technical judgement would tell them to do. In the past five years in regard to design margins, this point was made in the paper, and the selection of materials, the technical judgement had taken a second place, and very often the results had not been particularly satisfactory. This was not the result of the shipyard designs, or selection, and often came out of commercial pressures that existed when subcontractors were looking for business.

Mr. Coats was correct in stating that it was largely the higher capital cost of the gas turbine/electric installation which caused it to show up badly in Fig. 9. The cost of the machinery was built up from actual quotations, but in case it was considered too generous, an alternative solution had been worked with some changes to the data shown in Table IV. The ship cost was reduced by £0·5 million to £26·0 million and upkeep costs were reduced to £200 000 p.a. and crew costs were reduced to £140 000 p.a. (equivalent to a manning of about 30). These were the kind of savings that might be achieved with lower levels of maintenance and reduced manning. The revised gas turbine economic assessment was shown in Fig. 19 and could be considered as an optimistic view as the line on the right of the diagram was probably a pessimistic view of the gas turbine.

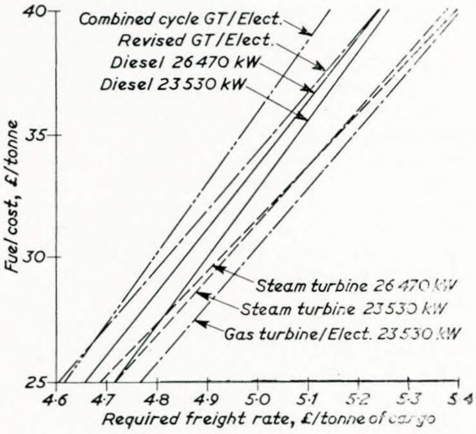

FIG. 19—*Economic analysis for VLCC with steam, gas turbine and slow speed diesel propulsion*

The authors had also looked at the possibility of a STAG cycle, although it was felt that it might be too complex unless it could be arranged in such a way that was very easy to operate. Using information supplied by Mr. Coats' company, an economic assessment was made of the STAG cycle using the Table IV gas turbine data as basic and the fuel consumption amended to 140 t/day at sea and 29 t/day in port. The total ship cost was increased by £260 000 and the result plotted on Fig. 19.

Considering the development of the reversing marine gas turbine, this was a great help in the cost area. Perhaps the combined cycle had the advantage that only one gas turbine could be used. The authors had chosen two because they wanted to run the machines at their full rating.

In reply to Mr. Bridle's comment on type testing of equipment, this was often done abroad, certainly on the major items.

With regard to design studies, the authors were not suggesting this should be done for every ship. If it were an established type it would not be necessary, but with something new it was always their experience that very little detailed thought had been given to it. Containerships were an example of this. Certain containership types were not given sufficient thought at the outset. The consequence was that everybody, including the shipowners' staff, was put into the position of trying to deliver something against production targets, when design considerations were often pushed aside, and people made judgments about the equipment and the installation, which in retrospect had been wrong. They were made, in fact, to enable progress to be made. What the authors were suggesting here was a good case for having a design study and having an intelligent look at even a single design and getting it properly developed before reaching the stage of placing an order.

With reference to the steam turbine cycles, this was a projection of the way current steam trends for large tankers and containerships were developing and was not intended to indicate that fuel costs were less important at the higher powers. The two-boiler reference was not meant to introduce any complexity into the reheat areas, but more to emphasize that the authors had always firmly believed that any steam turbine installation should have two boilers, and that however the reheat was arranged, it should be looked at still as a two boiler concept.

The change over to triple-reduction gearing would of course depend on the shaft speed and reduction ratios. The section on gearing in the paper emphasized 60 rev/min, as it was the intention to explore whether there would be any gearing limit from the use of future high output steam turbine sets at low revolutions.

The epicyclic secondary gear drive had not yet been developed in detail, but as there had been designs on the drawing board for some time which offered possible cost advantages, it was assumed that they would be tried in due course.

Table III was included in the paper to tabulate the possible changes that might occur in engine performance over the period considered, following certain engine developments outlined in the text. As such it was not felt necessary to comment further on the high speed diesel engine data.

With regard to converging design, looking at the aero-derived type of gas turbine, some of the newer generation required considerable changes to adapt them to marine use so that one came to the conclusion, as Mr. Cliffe did, that the stage had almost been reached for taking the best practice in each of these design areas and end up with a design particularly for marine use.

The authors had not dismissed the combined cycle altogether, as was implied. They had said that the combined cycle turbine, which they thought would be relatively simple, would be considered and this would have advantages in the area of fuel economy. They still felt, however, that the combined cycle with more advanced steam conditions would require very careful consideration before it was adopted; in fact, it was their view that it would not be.

With regard to the relative movement in capital cost and fuel cost of nuclear application, the fuel cost would now have a considerable advantage over the fossil fuels, but the capital cost perhaps might not have moved in the same order as the fossil fuels. They would accept that there could be an argument in economic terms suggesting nuclear power. Within ten years this would probably be a real development. They were only trying to look as far as 1985 and, although beyond that there would be such development, at this time they did not believe it would be an immediate development. One of the areas which required looking at very carefully was training, for this was one of the major problems at the moment in the operation of ships.

Mr. Yates had extended the argument for using epicyclic gears, but went further than the authors who were illustrating the epicyclic possibilities amongst other gearing developments.

Mr. Bell had commented on the gas turbine designs available from GE. At this time in the industrial gas turbine area it was the only design available. It prompted the question as to why British industry, having done so much in the early years of the gas turbine, did not have a design available now that it began to look a possibility. The amended data referred to by Mr. Bell was included in the reply to Mr. Coats.

With regard to Commander Middleton's remarks concerning the use of data to locate problems in the operation of machinery, the authors agreed that this was difficult, but there were examples in Scandinavia where this had been done with diesel machinery. It had been found possible to locate problems, admittedly with some significant movement of some of the measured parameters, and they were suggesting that this was the correct way to go.

They realized that it could not be applied generally, but certainly in the case of main machinery and other items of equipment it had been possible to look for and find ways of locating, or identifying, difficulties before they had developed and cost a great deal more money.

With reference to Mr. Cochet's remarks concerning medium speed plant, the authors had not deliberately neglected the medium speed and had predicted an increasing share of the market in Fig. 5. They accepted that it gave some freedom in the choice of engine speed. In a lot of the power ranges applied at this time it was not always possible, because of draught restrictions, to take full advantage of them. With regard to the two-stage turbo-application, this could be a naval application, but the authors would still hold the view that the cost increase might not be acceptable on this type of plant for the marine application.

In response to Mr. Cliffe's contribution, the authors had assumed that the gas turbine fuel would be treated. Fuel treatment was currently under development and Mr. Cliffe's comments were accepted. There would have to be proper treatment of the fuel. The authors, like Mr. Cliffe, would be reluctant to see a development of the reheating steam turbine, but they did not see any other way to go from the competitive point of view.

Mr. Victory was surprised at the reference to "get-you-home" capability. The authors had tried to stress this in the area concerned with insurance, as they felt that design consideration was not reflected in the insurance premium that was subsequently paid. Design capability, inert gas, braking arrangements, and the additional equipment that some owners installed to help in the navigation and general control of the ships, were not recognized at all when it came to insuring them. This was wrong and was hardly in the interests of the insurance industry itself.

With regard to sub-division of the engine room, there might in the larger ships be similar possibilities, not so much of sub-division, but, now that segregated ballast was becoming a requirement, not only could there be side bunkers, but there could be side tanks round the engine room, some of them carrying ballast. It was mainly the argument of expense that was against splitting the engine room up into entirely different compartments as in a Royal Navy vessel. Certainly from the noise angle it would have advantages, and some of the proposals for meeting the medical requirements with regard to noise would do just this. Certain noisy equipment would have to go into separate compartments, and it might well be that some designers were considering a "noise sanctuary" to which the engineer operating the plant could go for certain defined periods of the watch. Sub-divisions had some advantages from that point of view but it was doubtful whether economically it could be justified.

Mr. Spears's contribution commented on the economic assessment, and contrasted the results with the current order book for VLCC. The majority of these vessels were ordered before the large increase in fuel oil prices and at that time the authors' own calculations indicated a general superiority for the steam turbine plant.

The days in service for the different machinery types was always debatable and appeared to vary significantly between operating companies. It was the authors' intention to steer a middle course; they did not feel that gas turbine experience in base load electrical utility service was directly relevant to days in service at sea.

Both the slow speed diesel installations considered had waste heat units and turbo-alternators sized to meet the electrical load under normal service conditions. The economic assessment results were plotted against varying fuel cost so that the Required Freight Rate could be compared for any specific fuel quality or cost within the range considered.

Mr. Owen had also shown how the conclusion drawn from the economic assessment might be influenced by the fuel quality and cost. As stated previously, it was the authors' intention to look at average grades of fuel rather than extremes, which could be used to make out a better case for one or other of the competing machinery types.

The authors were interested to receive Mr. Owen's extension of the economic comparison for the reheat steam turbine, although they did not agree with his assessment of the days in service. From discussions the authors had had with owners and engine builders, an advantage of two days per year for the simple steam turbine cycle over the slow speed diesel seemed not unreasonable, but the authors' inclination would be to compare the reheat steam turbine with the slow speed diesel on an even basis.

Dr. Buxton had made a number of comments generally supporting the arguments in the paper. The long term consequences of the dramatic increase in fuel oil prices had yet to be evaluated, but there would obviously be changes in trade patterns, selection of machinery and level of powering which would have an effect on the data used to build up Fig. 5.

The speed of the vessels used in the economic assessment was based on a similar hull form to those in service, and an average value was taken for the loaded and ballast voyages. The authors agreed that if a precise assessment could be made of upkeep costs and insurance there might be a slight increase for the higher powered alternatives.

Mr. Kirton had already made the case for formal quality assurance procedures. It was the authors' intention to outline an overall design procedure which specified not only the material and machinery specifications, but also the tolerances and operating specifications which would become the basis for a higher standard of quality control. Normally the Quality Assurance Department would function within the context of the Engineering Production Department or as part of a total quality assurance organization—in either case, reporting directly to the most senior levels of management to ensure that short term considerations did not overrule quality requirements. The activities of the department must be integrated with the production programme and a commitment recognized for the completion date of the various stages of inspection, testing and commissioning. At the same time, individual decisions must be taken free from the pressures of the programme which could condition production decisions.

A previous contributor had also raised the question of improvements in salt water systems and the authors' views were expressed in answer to Mr. Bowers. There were numerous applications where an owner might be justified in paying a higher capital cost for equipment which would give longer life or reduced maintenance, and a capital appraisal approach similar to the economic assessment in the paper could be used to assess the economic savings for the owner over a specified period of the ship's life.