PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

Future Propulsion Systems for Merchant Ships

R. Munton

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Future propulsion systems for merchant ships

By R. Munton†
The Institute of Marine Engineers, 76 *Mark Lane, London E.C.* 3

The paper is primarily from an individual shipowner's viewpoint. The first part of the paper considers the likely trends with regard to main propulsion systems arising from that viewpoint. It takes into account the emphasis on reliability and safety, pollution problems, and the combination of capital and operating costs of the system.

Consideration is given to the various fuels used with prices and price trends. This is related to an analysis of the various types of propulsion systems presently available including gas turbine and nuclear power systems.

In the second part of the paper, the individual views are compared with those derived from a statistical investigation of trends in machinery installations related to ship types and sizes based on published data.

The conclusions drawn from the two approaches are in close agreement that in the 1980s the most widely used propulsion systems will be the slow speed diesel and the geared steam turbine with the main contenders being the medium speed diesel engine and the gas turbine. Nuclear propulsion is ruled out for this period because of pollution hazards and high capital costs.

1. Particular considerations

(*a*) *Shipowners attitudes*

Before dealing directly with the subject matter of the paper it is necessary to state the shipowner's general philosophy with regard to the use of new designs of machinery.

The owner's consideration of any difference in ship design must essentially be concerned with the effect of that difference on the economics of operation throughout the life of the ship. He is concerned with the total balance of earning power (cargo capacity, port turn-round time, speed, days availability per year), amortized capital cost and operating costs. General experience indicates that in changing from a known satisfactory design to a different design of any item of machinery brings the risk of loss in availability time and unexpected costs for maintenance.

'Different' does not necessarily mean 'new': one has seen many cases of an owner, operating satisfactorily with one particular class of machinery, switching to another quite successful design and running into trouble.

The reason, of course, is lack of operating experience, both by the engineering staff on the vessels and the owner's technical staff ashore. The degree of trouble in the changeover is governed by the quality of staff in both areas and particularly in the shore area.

There tends therefore to be some resistance to change, and certainly it is foolish to change unless there is a clear indication of economic advantage. Even in the selection of machinery from known satisfactory designs there tends to be some degree of justifiable bias on this account. No design of main propelling machinery is without its operating problems. Some of these can be eliminated by minor design modifications, others are inherent in the design and one has to learn how to live with them.

The author would not pretend that he is entirely free from bias derived from the experience of his company. It may therefore be well to briefly indicate the recent area of experience. The

† Present address: Technical Department, Cayzer, Irvine and Co. Ltd, Cayzer House, 2 & 4 St Mary Axe, London EC3A 8BP.

composition of the present fleet is shown in table 1 and brief comments on the various installations follow:

TABLE 1

type of vessel	machinery type†	no. of ships	age range years	max. service horsepower	max. service power MW	max. speed knots	max. speed m/s
passenger mail	s.t.	3	11–23	45000	33	22.5	11.5
cargo mail	s.s.d.	2	6	35000	26	22.5	11.5
refrigerated cargo	s.t.	1	12	11550	8.5	16.5	8.5
refrigerated cargo	s.s.d.	6	5–14	10500	8	17.75	9.1
dry cargo	s.t.	1	15	9400	7	15.75	8.1
dry cargo	s.s.d.	26	4—25	8500	6	16.5	8.5
bulk carrier	s.s.d.	3	1—4	16800	12	15.25	8
tanker	s.s.d.	1	12	10000	7.5	15	7.7

† s.t. steam turbine. s.s.d. slow speed diesel.

Passenger mail

When these ships were built it was not considered a feasible proposition to propel them by slow speed diesels without incurring the penalty of an expensive diesel installation, a large and high engine room and the possibility of inacceptable machinery induced vibration in the accommodation spaces. Furthermore, a power reserve of 10 or even 20 % could be incorporated in the steam turbines by means of a steam by-pass arrangement for a fraction of the cost of doing so in the diesels of those periods.

The choice today is wider, and ignoring for the present the elements expressed in the opening philosophy, it could include slow speed diesel of numerous configurations, medium speed diesel and gas turbine.

Cargo mail

Steam turbine machinery was considered at the design stage of these ships but was eliminated in favour of slow speed diesel on reliability, and economic grounds.

At present, the steam turbine would still be a contender and medium speed diesel and gas turbines would have to be added to the list for appraisal if similar ships were required.

Refrigerated cargo (steam turbine)

This class would not be repeated because of high fuel costs.

Refrigerated cargo (slow speed diesel)

This class is very satisfactory on all counts with slow speed diesel machinery but medium speed diesel and gas turbines would require consideration especially if replace ships were of palletized type with unconventional handling arrangements for the cargo and a low deckhead height requirement in the engine room.

Dry cargo

The remarks for refrigerated cargo ships apply.

Bulk carrier

This class also is very satisfactory with slow speed diesel machinery. The author would find difficulty in proposing a machinery type other than slow speed diesel in this class.

Tankers

Since the one 18000 tons dwt tanker in this class was built, the whole outlook on tankers has changed and the choice of machinery would depend on size and service. All types of machinery could be considered; steam turbine, slow speed diesel, medium speed diesel and gas turbine.

Container ships have not been mentioned but these would naturally fall within the requirements of passenger ships.

(*b*) *Considerations in choice*

Steam or diesel?

Over the years there has been this continuous controversy of steam versus diesel propulsion and cases have been produced, mainly by manufacturers, showing the economic superiority of one system over the other depending of course on the allegiance of that manufacturer to a particular system. Rarely is it possible even for a shipowner to make an unbiased direct comparison over a number of years of actual operating costs with two sister ships, one steam, one diesel, both of the same age, on the same service and operating staff of similar quality in order to obtain the factual information. Suffice it to say that in the author's company, experience of operating steam and diesel vessels of different ages and horsepower has resulted in the broad conclusion that the overall maintenance and staff costs between the two systems are not markedly different and that the diesel is slightly better in reliability and flexibility and more constant in fuel consumption costs. From this experience and when considering a new ship, the author's first preference is for diesel machinery of the slow speed type if it can be accommodated in the ship design concept depending on the power required, the space available, especially engine room height as already referred to, and any limitation on propeller revolutions. Only if the slow speed diesel were excluded because of these limitations, would steam turbine or medium speed geared diesel or other systems be considered.

Reliability

Reliability is the most important single factor in operating a fleet of ships especially mail ships or other ships on a tight service schedule. It follows, therefore, that a choice of machinery is made so that in the event of fault there is sufficient flexibility in the system and reserve of power to allow the ship to maintain schedule. With the modern diesel this is generally more easily attained than with turbine because a defective component will normally result in reduction of power in one cylinder only. Additionally, there may be a period of stopping while the cylinder is isolated, but even then if reasonable reserve power has been installed in the first instance it should be possible, especially in the early period when teething troubles may be anticipated, for the ship to make up time and arrive on schedule. With the steam turbine, trouble is normally of a serious nature such as damage to a turbine rotor which may reduce the power very substantially. On the other hand, it may be a boiler which would reduce the power by one third on a three boiler ship. These things do happen and will continue to happen in merchant marine installations where it is not financially practicable to carry out full prototype testing under service conditions, but the system design should be such that whatever the method of propulsion the incidence of fault should result in the least reduction in power, when spread across even the auxiliary range. Table 2 shows a comparison over the last six years of the number of times two diesel and five steam turbine mail vessels have failed to keep schedule due to machinery defects.

Table 2. Number of occasions of mailship delays due to machinery defects

type of ship	typical reasons	delay in hours: up to 6	6–12	12–24	24 and above
2-vessels (s.s.d.)	turbo-charger failure, cylinder liner failure, minor defects	2	1	2	2
5-vessels (s.t.)	turbine, boiler, condenser, boiler fan, economizer tube defects	4	1	—	4

(c) *Economics of choice*

Steam turbine

For each type of system there are credits and debits. For the steam turbine system on the credit side there is greater flexibility in the choice of operating revolutions for the propeller. On the low end of the range this sytem can enable large tankers to operate at around 80 rev/min and obtain maximum propeller efficiency. At the other end it can allow high speed container ships with limited draft conditions to operate with high revolutions, say 140 rev/min, and thus obtain the power required on a reduced diameter of propeller albeit with a penalty on propeller efficiency. The operating conditions on steam turbine vessels are usually more agreeable for the engineer officers because of the lower noise level in the more modern ships and the generally cleaner conditions.

On the debit side there is a penalty of a high fuel consumption of around 200–213 g per shaft horsepower hour†. The settings for optimal fuel consumption still require some manual intervention and judgement, so that the performance of the machinery is more dependent on the experience of the operator than is the case with the diesel. In addition, the system does not lend itself to any unattended operation without having a large number of complicated control systems. More care is required with boiler operation to avoid pollution of the environment with smoke, especially during the period of lighting up the boilers and any subsequent low load periods in port and manoeuvring out of the port. A further disadvantage of steam turbine systems is the restriction of astern power to between 50 and 60 % of ahead power. With the advent of more powerful control pitch propellers this disadvantage will disappear.

Slow speed diesel

To the credit of the slow speed diesel, there is a lower specific fuel consumption of about 156–168 g per shaft horsepower hour using the same heavy fuel as used in the boilers of the steam turbine ship. It is customary to use the waste heat from the exhaust gas to generate steam for various purposes. In the author's company six ships are additionally fitted with turbo alternators using this steam which improves the all purposes fuel consumption based on horsepower to approximately the same figure as the main engine only. Furthermore, the combustion is better in the diesel resulting in clear exhausts. The fuel consumption is more constant because

† 1 horsepower hour ≈ 2.7 MJ.

the optimum conditions are set on the test bed and can be maintained in service. On the debit side there is the difficulty of overhaul with the large units having to be handled but paradoxically the diesel ship lends itself better to crew maintenance overall than does the steam turbine ship. The slow speed diesel engine requires an expensive lubricating oil for cylinders and the usage of this is relatively high at about 0.5 g per horsepower hour.

For unattended operation the controls required for the diesel engine installation are relatively straightforward. At the present time there are more diesel ships at sea equipped for the non-continuously manned operation of the engine room than there are steam ships.

Medium speed diesel

The medium speed diesel has tended to supersede the slow speed diesel and the steam turbine in vessels where deckhead height is limited such as in cross-channel steamers, car ferries, etc. It is naive to expect that trouble-free machinery can ever be installed in a ship. This is especially so at the present time as power to weight ratios increase especially for the medium speed diesels and the steam turbines and gas turbines. Such designs call for a high standard of technology coupled with first class manufacturing facilities and quality control. There is abundant evidence that these standards have not reached a satisfactory pitch as yet. On maintenance the author finds it difficult to accept for a medium speed installation an increase in the number of cylinders requiring attention of four or five to one for the same shaft horsepower. There is no convincing evidence that the time taken to service the cylinder of a medium speed engine is appreciably less than that of the slow speed engine.

Gas turbines

The author would not at this stage consider gas turbine propulsion because of the relatively untried machinery, the unknown factors in maintenance and in servicing time, the higher costs of fuel, and the difficulty of ensuring satisfactory arrangements for air supply to the turbines and the exhausting arrangements from them. On specific fuel consumption, figures vary widely from 160 to 220 g per horsepower hour but many of the systems having the lower specific consumption are still on the drawing board.

Nuclear power

The author does not consider the nuclear power system a feasible proposition because it would be grossly uneconomic both in capital costs and in manpower on board and could not be justified for any commercial operation. In addition, there is the great danger of pollution which can happen if there is an accident on board or collision. Figure 1 shows Lloyd's records of casualties since 1949. Recent incidents in the English Channel well known to everyone here, including *Torrey Canyon*, emphasize the great dangers present if there were numerous nuclear ships open to risk of collision and stranding. It is the author's firm opinion that the right place for nuclear power is in shore power stations except for naval vessels where special considerations apply.

Safety

On safety, fires and explosions can occur on all types of machinery installations. World records are not sufficiently comprehensive to show whether diesel ships are worse than steam ships but certainly in the author's experience there is a higher incidence of fires, not necessarily

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external fires, and explosions on diesel ships than on steam ships. The risk of catastrophe may be higher on the diesel than on the steam but constant vigilance on the part of the operating officers is necessary whatever the propulsion system may be.

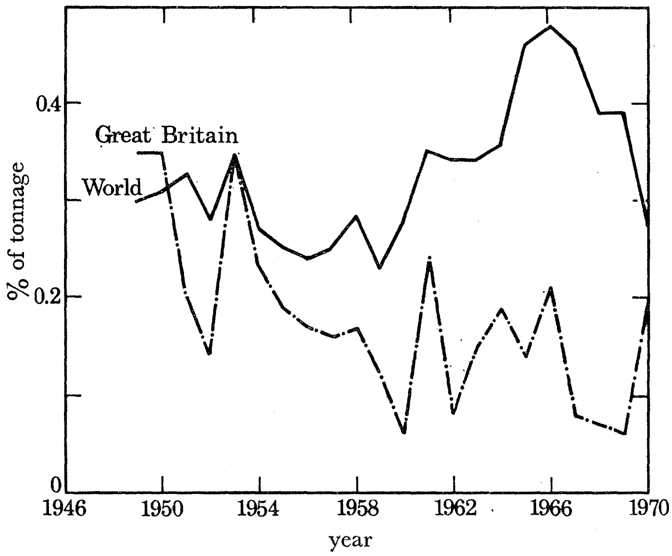

FIGURE 1. Great Britain and world percentage of fleet tonnage losses at sea 1949–70 ships of 100 tons gross and above from Lloyds Register of Shipping Statistical Tables 1971.

Relative costs

Table 3 gives some indication of the expected relative capital costs of vessels with steam turbine, slow speed diesel, medium speed diesel, gas turbine and nuclear propulsion and the expected fuel and maintenance costs including lubricating oil of these ships. It is difficult to be precise about them but those on capital costs are considered to be reasonably accurate in present conditions. The figures suggest that the diesels on heavy fuel would have the advantage over the steam turbine on fuel costs by a factor of 20 % and the slow speed diesel would have the advantage over the medium speed diesel in maintenance costs and overall reliability.

TABLE 3

	total machinery cost	fuel lub oil cost	reliability	mainten-ance	ship design flexibility	pollution
steam turbine	100	100	basis	basis	basis	basis
slow diesel	89–100	84–80	plus	basis	minus	better
medium diesel	98	94	plus	plus	plus	better
gas turbine	106–109	133	minus	?	basis	basis
nuclear	174	70–80	plus	basis	minus	worse

(*d*) *Fuels*

Steam turbine and the slow speed diesel ships use heavy residual fuel oils of up to 3500 s Redwood no. 1 without difficulty. The writer is not entirely satisfied that the medium speed diesel can use even 1500 s fuel satisfactorily. The aircraft gas turbine derivative used for marine work can only burn distillate fuels and although it is claimed that the industrial gas turbine can use residual fuels it is probable that these fuels have to be specially treated and care taken to prevent undue fouling of the turbine blades. Shipowners endeavour to have a propulsion system that can accept practically any fuel which is offered anywhere in the world, otherwise the price tends to increase for a required specification. Figure 2 shows prices of distillate and residual fuels over a period and indicates the benefit of using residual fuels.

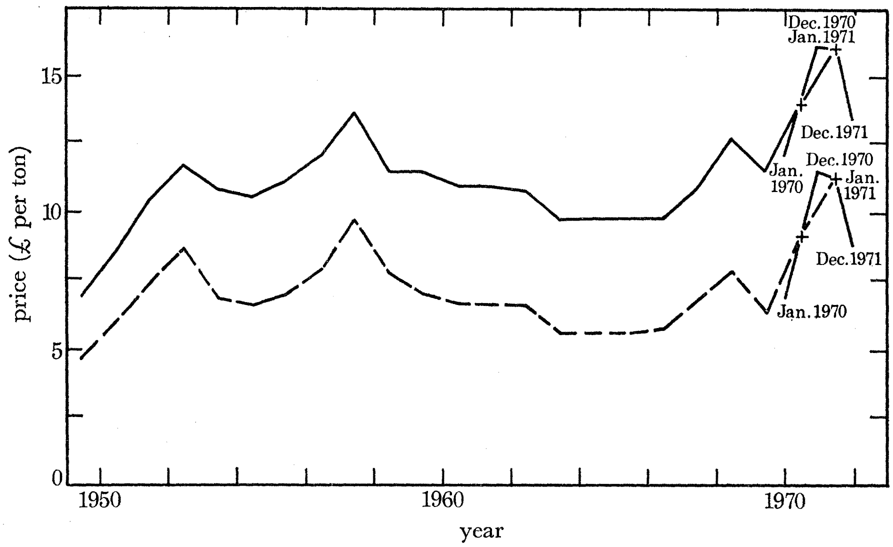

FIGURE 2. Bunker oil prices at United Kingdom ports. Yearly average contract prices 1949–72. Data extracted from British shipping statistics 1969–70 and Chamber of Shipping of U.K. ---, fuel oil; ——, diesel oil.

(e) *Present propulsion systems*

The steam turbine is produced in a variety of designs with many operating at a boiler pressure of 6.4 MPa (64 bar) and steam temperature of 510 °C. The largest installations have up to 60000 horsepower (45 MW) on one shaft, but this is not necessarily a limit. Depending on the service it is possible to have one or two cylinder designs with double reduction gearing, the first reduction being generally of epicyclic type.

Slow speed diesels are produced in various types and sizes with power per cylinder up to 4000 horsepower plus (3 MW), in a maximum of 12 cylinders, each of around 1 m bore and 2 m stroke. For these large sizes the revolutions are about 100/min.

Medium speed diesels can now be obtained at 1000 horsepower (750 kW) per cylinder in in-line and V configurations up to a maximum of 18 cylinders in V form i.e. 18000 horsepower (13 MW) at 425 rev/min. The propeller shaft is driven through clutch and gearing and generally a controllable pitch propeller is used to provide reversing and some torque control.

Gas turbines are offered as aircraft type modified for marine use or the heavier duty industrial types. Gas turbines of 30000 horsepower (22 MW) per shaft of the first type are in service in a container ship.

(f) *Future systems*

As the author sees the future, the four propulsion systems using fossil fuels above will continue into the foreseeable future. There is scope for better efficiency in the steam turbines and boilers possibly at the price of greater complexity and even reduced reliability, but this could be overcome by better design, simplification of controls and more skilled maintenance possibly on aircraft lines.

The slow speed diesel may not have reached the end of its development and output per cylinder of 6000 horsepower (4.5 MW) may be practicable with cylinder bores of 1.2 m.

The medium speed diesel still has great potential and designs are now on the test bed of up to 2500 horsepower (2 MW) per cylinder.

The gas turbine will have an application in some services where the financial benefits of high power and low weight are of greater importance than fuel costs.

To sum up, the author's ranking and choice of propulsion systems for the future would be:

high powers above 30000 shaft horsepower (22 MW)	1	slow speed diesel	large tankers container ships
	2	steam turbine	
low powers below 30000 shaft horsepower (22 MW)	3	slow speed diesel	bulk carriers dry cargo refrigerated cargo
	4	medium speed diesel	

This is of course subject to ship design limitations.

2. General and statistical considerations

After having considered the propulsion systems from an individual viewpoint, it is necessary to examine the international position, using published information and statistics.

Figure 3 shows the distribution of the principal propulsion systems over the world fleet of merchant ships for the past eight years. Probably the most revealing curve is that for steam reciprocating machinery which although declining still represents about 10 % of the steamships; this indicates the time scale to get rid of the obsolescent. It will also be observed that over the

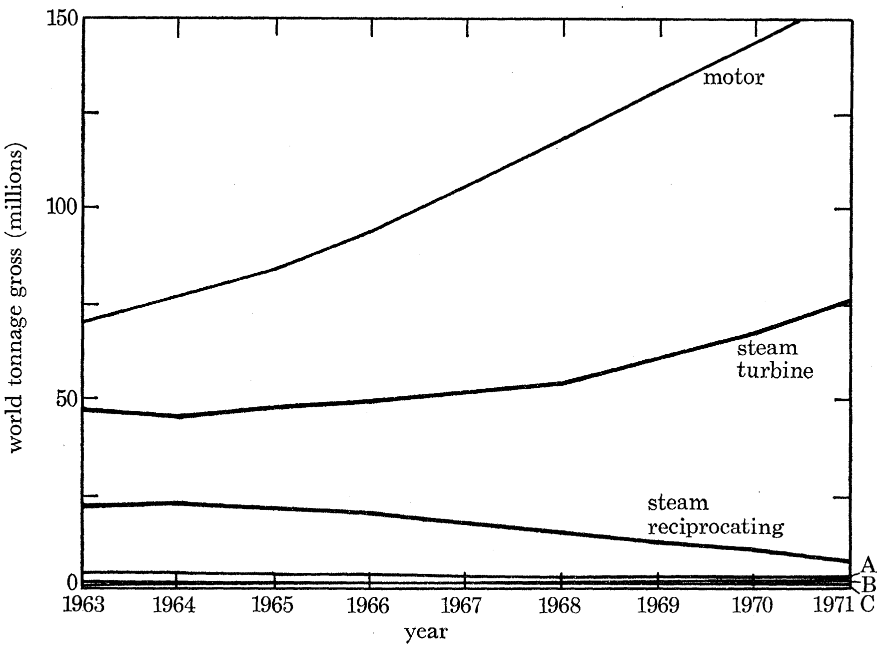

Figure 3. Propulsion analysis of world tonnage for ships of 100 tons gross and over data extracted from Lloyds' Statistical Tables 1963–71. *A*, turbo-electric; *B*, diesel-electric; *C*, reciprocating and turbine.

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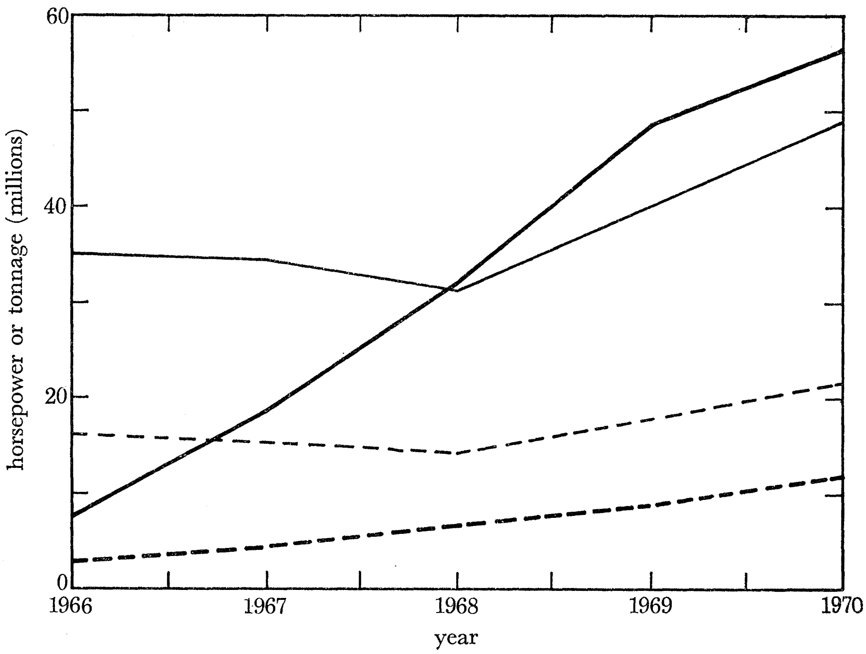

Figure 4. World order book position ships of 2000 tons deadweight and above (derived from statistics compiled by *The motor ship*). ——, aggregate steam deadweight tonnage; ——, aggregate motor deadweight tonnage; – – –, aggregate steam shaft horsepower; - - -, aggregate motor shaft horsepower.

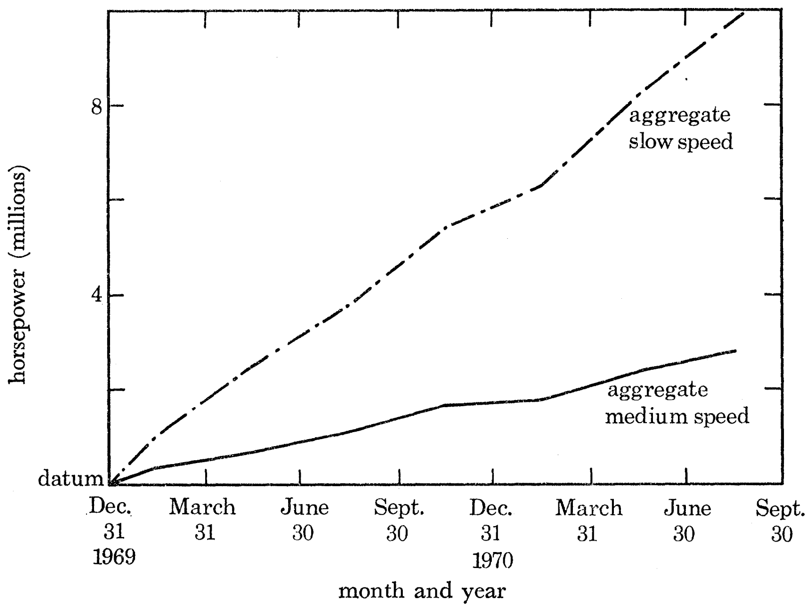

Figure 5. Medium and slow speed diesel engine installation from statistics compiled by *The motor ship*.

last two years steam turbine ships have increased by 7.5 millions tons gross per year while diesel ships have increased by 12.5 million tons gross per year.

For the same eight year period, the world order book increased from 28 million tons dwt representing 1350 ships and 17 million horsepower (13 GW) to 140 million tons dwt, 2800 ships and 41 million horsepower (30 GW) in 1971. These 1971 figures reflect the increasing size of ships which will be coming into service over the next two/three years.

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Figure 4 gives an analysis of the world order book position divided into steam ships and motor ships since 1966, and indicates clearly the increase in diesel tonnage ordered since 1968.

In Figure 5 a comparison is shown in the relative growth rate of the slow speed and the medium speed diesels, the former having the faster rate.

The present depression in shipping freight rates is having an adverse effect on shipbuilders' order books, but the exact figures for these are not yet available. The number of gas turbine installations is too insignificant to be indicated in the statistical tables, though there are now a few ships with gas turbine machinery designed as commercial units in service or on order.

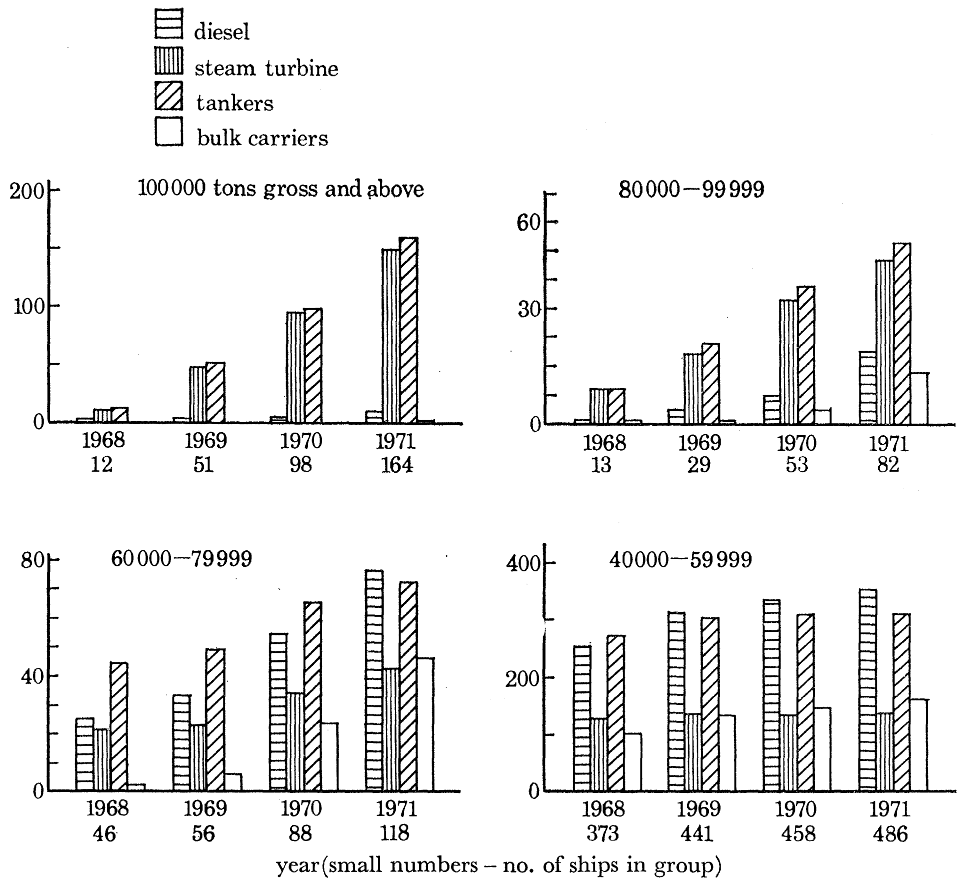

FIGURE 6. Ship type propulsion analysis in tonnage groups.

Figure 6 gives the propulsion analysis in tonnage groups for tankers and bulk carriers and illustrates clearly the preference for diesel at the lower tonnage and steam turbine for the very large ships, but there is indication of some increase in diesel tonnage in this higher range. An inspection of the orders in *The motor ship* and *Fairplay* reveals the following:

steam powered vessels			
ship size range (tons dwt)	173000	—	256000
power range (horsepower)	28000	—	40000 (21–30 MW)
diesel powered vessels			
ship size range (tons dwt)	224000	—	280000
power range (horsepower)	34200	—	38000 (25–28 MW)

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Figure 6 also shows the numbers of tankers and bulk carriers in four tonnage ranges. Although the increasing number and size of bulk carriers in the higher tonnage range is clearly seen, and this will of course include ore/bulk/oil (o.b.o.) ships, the increase in number and size of tankers is even more noteworthy.

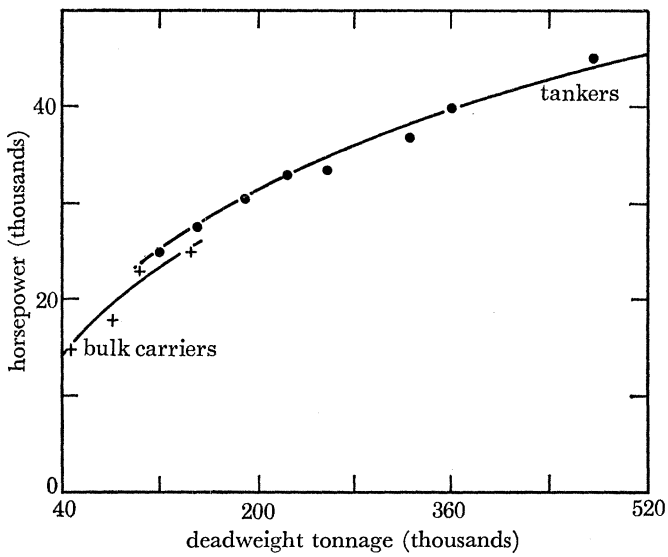

FIGURE 7. Power deadweight curves for tankers and bulk carriers on order February 1971 data extracted from ships on order supplement to *Fairplay*.

Figure 7 shows power/deadweight curves for tankers and bulk carriers on order in February 1971, and indicates a range of up to 25000 shaft horsepower (18 MW) for bulk carriers and from 25000 to 45000 shaft horsepower (18–33 MW) for tankers. It is obvious from figures 6 and 7 and current orders that all of these powers can be developed in steam or diesel machinery.

The following table 4, taken from *Fairplay*, shows the world order book for container ships end of November 1971:

TABLE 4. WORLD ORDER BOOK FOR CONTAINERSHIPS† AT NOVEMBER 1971

			diesels		
data title	Σ	steam turbine	slow speed	medium speed	gas turbine
number of ships (N)	211	80	92	37	2
% of ΣN	—	38	43.99	18	0.01
power‡ (P)	6832224	4122050	2015984	574200	120000
% of ΣP		60	30	8	2

† All containerships with capacity of 300 or more ISO 20 ft. containers. Includes following types: container/barge carrier, container/liner, containership, container/pallet ship, container/part refrigerated, container/ore carrier, container/trailer ship, and container/railcar carrier.

‡ For steam turbine installations power is in S.H.P.; for diesel installations power is in B.H.P.

Compiled from information contained in *Fairplay* world ships on order November 1971.

World order book for containerships at November 1971

Included with steam turbine ships are eight ships each with maximum horsepower of 120000 (90 MW) on twin screws. In the slow speed diesel column the highest powered ships are three container ships each with 77300 horsepower (58 MW) on triple screws, and a total number of cylinders of 30 per ship.

In the medium speed engined ships, there are four ships each with a total of 27000 horsepower (21 MW). For the gas turbine, there are two ships remaining of this order, each with twin screws and total of 60000 shaft horsepower (45 MW).

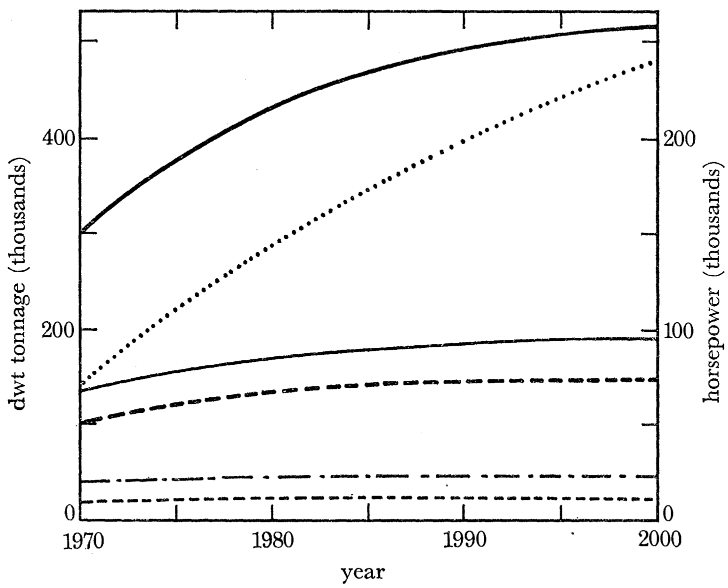

FIGURE 8. Largest ship/power predictions 1970–2000 reproduced from oceanbourne shipping demand and technology forecast by Litton Systems Inc. Tankers: ——, dwt; – – –, horsepower; bulk carriers: ——, dwt; ——–—, horsepower; dry cargo: - - -, dwt; · · · · ·, horsepower.

Figure 8 is based on the 'Litton' Industrial Survey, and indicates the increasing size and shaft horsepower of ships from 1968 to the year 2000. Already events have anticipated the forecast and a 477000 tons dwt tanker is now on order for delivery in 1973; the 'Litton' graph predicted this development in 1986. The horsepower for this steam turbine tanker is 45000 (33 MW) whereas the 'Litton' Survey predicted a power of about 70000 horsepower (53 MW).

For bulk carriers the demand for size has again anticipated the 'Litton' prediction, but in this case the horsepower required is greater than the 'Litton' forecast.

The dry cargo ships referred to in figure 8 are obviously fast container ships with high projected shaft horsepower, which does not make economic sense to the author.

The following occurrences since the 'Litton' Survey was completed may affect some of the predictions in that document:

(1) The present severe shipping depression.
(2) The concern about pollution of the seas and environment generally.
(3) The explosions in the cargo tanks of very large tankers and o.b.o.
(4) The structural problems in very large vessels.

The foregoing statistics indicate the growth and demand for large ships with higher powers and if the 'Litton' Survey is used as a guide these powers would be in 1985

(1) *Tankers* 70000 shaft horsepower (52 MW)
(2) *Bulk carriers* 22500 shaft horsepower (16 MW)
(3) *Containership* 175000 shaft horsepower (135 MW)

Compared with the present order books these represent increases of 55 % for the tanker, nil for the bulk carrier and 45 % for the containership, thus, the machinery available today could be used to develop even the highest power but a triple screw installation would be required.

For nuclear ships, the author can do no better than to refer to the 'Report on the nuclear ship study' published in 1971 by H.M. Stationery Office. In this document it was stated that tankers of 400–500000 tons were selected as being the smallest requiring the 60–70000 shaft horsepower (45–52 MW) for nuclear propulsion to be potentially competitive with conventional propulsion. For container ships, the upper limit chosen for study was 130000 shaft horsepower (98 MW).

The conclusions drawn from the study were that the capital costs of the nuclear ship would be between 18 to 40 % higher than a conventionally powered ship depending on investment grants and interest rates and that government support for a nuclear ship project could not be recommended at the present time. It was also stated that there seems no prospect of nuclear propulsion proving commercially competitive in the next two decades.

3. Conclusions

The conclusion can fairly be drawn from both § 1 and § 2 that in the immediate future and into the 1980s the most widely used propulsion systems will be the slow speed diesel and the geared steam turbine with the medium speed diesel contending strongly with both systems for a substantial portion of the horsepower range. The gas turbine will increase its hold especially in special purpose ships such as gas carriers and other applications which may suit a shipowner's requirements. Nuclear propulsion is ruled out on cost alone without having to consider the pollution risk aspect.

The author would expect that for tankers and bulk carriers up to 30000 horsepower (22 MV), the diesel installation would be the general choice and beyond that the steam turbine would predominate as the power increased, but this would be influenced by the owner's preferences.

For the higher powered container ships considerations of owner's preference for steam or diesel also apply. The author would prefer a diesel installation but limited to twin screws which would put a ceiling on power of about 70000 shaft horsepower (52 MW) if the machinery could be accommodated in the hull. The triple screw diesel installation would have advantages for maintenance in that one engine could be stopped for overhaul between ports when the schedule allowed.

It would have been gratifying at this stage to have announced the introduction of a new propulsion system for the future with all the advantages required of it. Alas, this cannot be done and in the author's view the type of machinery available now will be produced into the foreseeable future with steady development and improvements continuing as now to reduce overall costs.

Some new systems have been considered but they are not yet sufficiently promising to justify a thorough appraisal. These include fuel cells, magnetohydrodynamic production of electricity, and electric instead of geared drive for turbines and medium speed diesels with superconducting motors.

Taking time lag for development and the time lag for ordering and delivering, it is not considered that either gas turbines or nuclear power or any new system could really start to make an impact before 1980 in ship deliveries.

A very optimistic assumption would be that one of these systems, or all combined, grew from practically nil in 1980 to 50 % of delivered tonnage in 1989, or say, 25 % of the tonnage delivered in the 1980s.

It might also be assumed that the tonnage built each year covers the scrapping of 20 year old tonnage plus a growth rate of 7 % per annum.

On these two assumptions in 1989 the new systems would only be of the order of 10 % of the world fleet. This is scarcely a major change in composition and the great bulk of the world fleet propelling machinery would still be slow speed diesel, geared steam turbine and geared medium speed diesel.

Whatever the prime mover it would be expected that very few installations in the 1980s would not be designed on a non-continuously manned basis, with routine checks at 6 to 12 h intervals. The staff would be adequate to cover for the normal routine maintenance on voyage and on long voyages for a breakdown condition.

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References

Batten, B. K. 1971 Marine machinery failures. *I. Mar. E.* **84** (9).
Department of Trade and Industry 1971 'Report on the Nuclear Ship Study', H.M.S.O. London.
Fasse, Ir. J. 1968 Some considerations by a shipowner on the selection of main propulsion machinery for cargo ships. *Proc. I.M.A.S.* Section 4/c. 1. Mar. E. page 4c/1.
Hamada, Noboru 1971 Tomorrow in shipping and shipbuilding. Japan: Bureau of Shipping, Ministry of Transportation.
Jung, I. K. E. 1969 Steam turbine machinery, *Trans. I. Mar. E.* **81**, 137.
Short, K. I. 1971 Operational experience with medium speed diesel engines. *I. Mar. E.* **84** (2), 37–72.

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