IRRATIONALITY OF MARINE GAS TURBINE SHIP COST-EFFECTIVE ANALYSES

BY

HOWARD A. PETERSON

This paper was originally presented at the ASME Gas Turbine Conference held in Brussels in May, 1970. The Author, who holds a B.S. in Civil Engineering and a M.S. in Naval Architecture and Marine Engineering, is in the Office of the Assistant Secretary of Defense for Installations and Logistics, U.S.A.

A common deficiency in analysing various ship propulsion systems seems to be that most of our attention is directed toward finding out how well a new concept can carry out old missions. Very little effort is devoted to establishing important new missions that cannot be performed by older propulsion systems and visualizing new concepts of gas-turbine ships that are capable of those uses. To put it another way, we give most of our efforts to analysing the similarities of various propulsion systems instead of assessing their meaningful differences.

We all have seen many cost/effectiveness analyses of steam-propelled ships and gas-turbine-powered ships. The modelling is done on the premise that the systems are equal except for the propulsion plants. The models used are, in essence, empiric models for steam propulsion, inapplicable rules of thumb, comfortable patterns of operation and vested professional interests, all of which, in sum, are dangerous obstacles to an objective evaluation of marine gas-turbine propulsion systems—or any new ship propulsion system, for that matter.

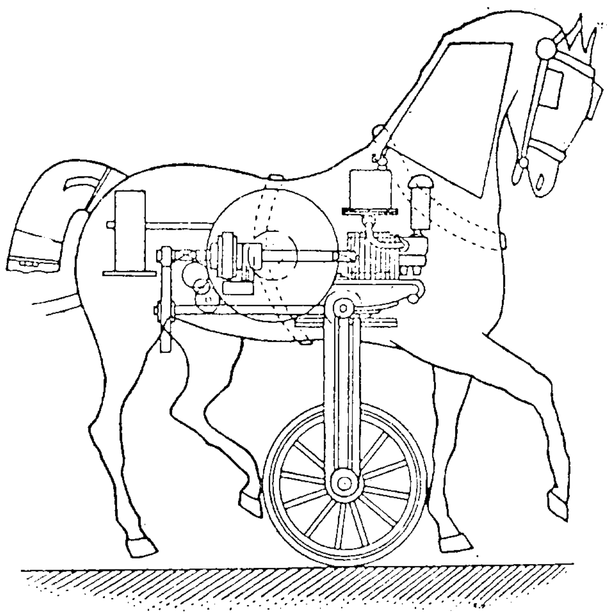

FIG. 1—THE MECHANICAL HORSE

FIG. 1 graphically illustrates this problem. Apparently the French inventor who obtained a patent on this internal-combustion contraption in 1897 was attempting to improve on the horse's mission rather than establish new missions in vehicle locomotion. It is most important that we understand the new potential of a new power system early and well. If we do not, the results will be vehicle designs that not only fail realize the new power system's potential but generate no logical reasons for changing over from old or current machinery.

The real problem, then, is to devise methods of measuring the differences in effectiveness between the old and the new systems when they are operating in roles, configurations and profiles especially tailored to maximize the use of each system's full potential.

HISTORY

Since it could well be that we are not doing much better today, it may be profitable to delve back into history and speculate on two eras of indecision and vacillation regarding propulsive methods—steam *v* sails and oil *v* coal.

Steam v Sails

Not long ago the sailing ship, which climaxed in the famous Yankee Clipper, was unchallenged on the seas. Sometime around 1800, the steamship appeared on the horizon, and in 1814 the USS *Demologos*, the first steam-powered warship was built for the U.S. Navy.

Even after this early exploitation of steam, the U.S. Navy went through some 80 years of hesitation and uncertainty before fully accepting steam as a means of marine propulsion. As early as 1814, there were five commercial steamers operating on the Thames, and the *Savannah* made her historic crossing of the Atlantic in 1819. But it was not until 1893 that the U.S. Navy finally shook loose the shackles of sails.

An interesting highlight of these 80 years of cautious indecision came in 1862, when John Ericsson built the screw-propelled *Monitor* ship for the U.S. Navy.

The contract for the *Monitor* required the builders to 'furnish masts, spars, sails, and rigging of sufficient dimensions to drive the vessel at a rate of six knots per hour in a fair breeze of wind.' This clause was ignored by Ericsson and apparently was forgotten by the Navy Department, for the *Monitor* had no capacity to carry sail. The contract also stipulated that, if the vessel failed in speed or other particulars, all moneys paid should be refunded to the United States. Not surprisingly, the ship failed to meet the contract's requirements for speed and also some other aspects, but fortunately for the contractors and the Union the *Monitor* passed its supreme test in battle with the Confederate ship, *Merrimac*, and the contractors were paid in full within a week after that epic encounter.

Afterwards, the London *Times* commented on the *Monitor's* effectiveness, not on her cost:

> 'Whereas we had available for immediate purposes 149 first-class warships, we have now two, these two being the *Warrior* and her sister *Ironsides*. There is not now a ship in the English Navy apart from these two, that it would not be madness to trust an engagement with that like *Monitor*.'

Though the Civil War gave a decided impetus to steam, a few years later, in 1869, Navy Department General Orders still decreed that:

> 'Hereafter all vessels of the Navy will be fitted with full sail power. The exception to this will be the tugs and dispatch vessels not fitted with sails.'

No doubt there were innumerable studies—even some on cost/effectiveness—comparing sailing ships and steamships. Today, we are very apt to say that hindsight is better than foresight, so it would be wrong to assume that designers of that period were just mentally dense and unimaginative.

Speculation on Former Effectiveness Models

While looking into past years, we may find it profitable to speculate on some aspects of analytical models that could have been used to compare one sailing ship with another, especially if we can thereby learn something that will help in today's modelling. Also, it would be fairly safe to assume that analytical modelling for sailing ships dominated the inputs and techniques applied to later modelling for steamships.

(1) *Endurance* was as important then as it is now. In the days of sailing ships, it was a function of their capability to carry food and potable water. Fuel-oil capacity and precise but misleading engineering studies on specific fuel consumption were not in the equation at all. The mere fact that the endurance of sailing ships was figured in months made the newfangled steamships come in a poor second, since their endurance was computed in hours—in some rare cases, days.

(2) The *speed* of sailing ships must have been thoroughly studied and the findings exploited. The Yankee Clippers were among the world's fastest ships. It is fairly sure, however, that speeds at all points of the compass and in conditions of no wind and light wind were not considered in the model. So here, too, steamships had little to offer, as the early ones could not attain the maximum speed of sailing ships, especially under favorable conditions.

(3) *Life-cycle* cost, or total cost of ownership, must have been a matter of primary concern, as it is today. Here, again, the steamship was at a disadvantage; the sailing ship had an sfc of zero, a much simpler power plant whose parts were universal with those of every other sailing ship, and perhaps a manning advantage, since the crew members who manned the sails were available for other duties during most of the voyage—but this was not so for the black gang and valve twisters on steamships.

(4) *Other model elements* as well, such as payload weight fraction, maintenance, etc., no doubt were carefully considered, but they also put steam at a disadvantage.

Many model elements, including these, were valid in comparing one sailing ship with another, but they were far from adequate in comparisons of sailing ships *v* steamships. In analysing warships powered with sails or steam, suppose one additional element were introduced to the model—'which ship, sail or steam, would have the greatest probability of defeating the other in battle.'

Normally the steamship should be able to bring its weapons to bear on the sailing ship and avoid the other's guns at will. This one additional element, had

TABLE 1—*Systems Analysis of Sailing Ship and Steamship*

Analysis Element	*Sailing Ship*	*Steamship*
Endurance	Unlimited	Very limited
Speed	Up to 20 knots	Over 21 knots
'Cold iron' to 100 per cent of full power	Well-trained crew less than 45 minutes	Up to 48 hours
Commonality of repair and spare parts with all other ships	Very high—nearly 100 per cent	Very low
Propeller cavitation at maximum speed	None-existent	Major problem
Underway replenishment requirements	'Beans' and bullets	NSFO, boiler tubes, 'beans', bullets, and a very long list of machinery spares
Acoustic signature	Low	High
Magnetic signature	Almost zero	High
Radar signature	Low	High
Ratio of payload to maximum displacement	High	Low
Life	Up to 100 years	Less than 50 years
Life-cycle cost	High	Very much higher
Sum of advantages	+11	+1
Best ship from analysis	Sails, by 11 to 1	

it been in the early model, could have shortened or eliminated the subsequent period of indecision. And, if some other elements had been considered as well—manoeuvrability, burst speed, target area, etc.—they could have pointed out the course more clearly. These elements of enhanced military effectiveness no doubt led to the *Monitor* and a short spree of building several *Monitor*-type ships. This trend toward steam was short-lived, however, and the analysts and engineers must have soon made the mistake of assuming that sailing ships and steam-ships were equally effective, with the consequence that, on the basis of cost modelling alone, the sailing ship was determined to be the winner.

Merchant Shipping

In the case of merchant ships, it might have been a little more difficult to shorten the time of indecision concerning steam. Here, too, elements dealing with customer service and total cost to the customer could have received more attention. With the sailing ship, the expense of warehousing, hotels and drayage was high owing to the impossibility of maintaining predictable sailing schedules.

Perhaps straightforward economic considerations would not have clearly dictated the course that should have been taken, and the more intangible aspects, such as man's desire to be associated with the predictable rather than the unpredictable should have been model elements as well.

TABLE 1 qualitatively summarizes the flavour of cost/effectiveness studies that must have been made during the 1800's. Chances are that basic errors were

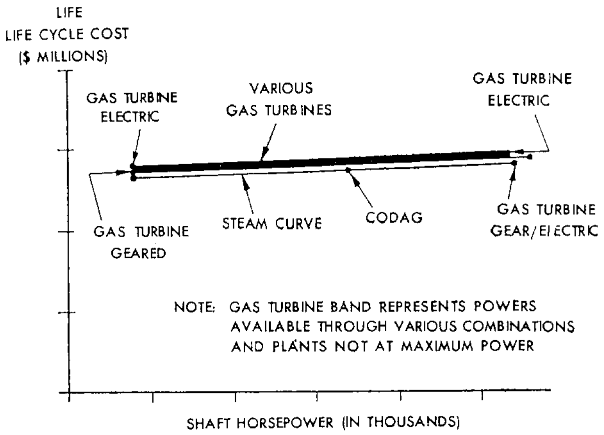

FIG. 2—LIFE-CYCLE COST COMPARISON—NSFO AND MARINE DIESEL FUELS

made not in cost comparisons but in effectiveness comparisons.

Oil v Coal

The second era in marine propulsion that we will consider involved oil *v* coal for propelling steamships. A sense of some of the factors considered by our forefathers can be gained from the historical note taken from a *U.S. Navy News Bulletin:*

> April 17, 1866—Congress appropriated $5000 to test the use of petroleum oil as fuel for ships' boilers. After the test the Bureau of Steam Engineering concluded that 'convenience, comfort, health, and safety' militated against petroleum. The advantages of oil were listed as 'less amount and weight of fuel' required.

Even from the viewpoint of elements considered, these conclusions are perplexing. Such improvements in military effectiveness as freeing prime midship space used for coal bunkers and utilizing normally wasted space between floors and frames for oil, greatly improved watertight integrity, improved mine and torpedo protection, time to refuel and be back on the line to fight efficiently, and changes in manning are not mentioned. In short, the elements by which the fighting effectiveness of the two systems could and should be measured appear to be lacking.

Reflecting on these two eras, we may infer that (*a*) sail economics and analyses must have been used to evaluate the steamship, (*b*) coal economics and analyses must have been used to evaluate oil, and (*c*) analytical models that could have dramatized the important commercial and military differences in the two systems' effectiveness received very little attention.

There is strong evidence pointing to the conclusion that, since rigorous mathematical models that could have established the military and commercial worth of steam propulsion over sails and of oil over coal are difficult to construct, they were excluded and that only those factors that were easier to evaluate were included. Further, from an objective viewpoint, that is exactly our course today.

Frequently we engineers have side-stepped the issue, and the way has often been indicated by evolution and the subjective assessment of non-technically orientated leaders. It took President Lincoln to make a subjective decision to build the *Monitor* steam combatant ship, Sir Winston Churchill to spur the shift from coal to oil, and President Kennedy to shoot for the moon.

INADEQUACY OF CURRENT ANALYSES

The main purpose of this article is to advocate the principle that measures of machinery effectiveness are essential to analytical systems modelling and to suggest that, before a ship is designed, appropriate effectiveness models be developed so that they have an opportunity to drive the subsequent design.

FIGS. 2 and 3 portray life-cycle comparisons of ship concepts employing steam Diesel and gas-turbine propulsion plants. Some people could—and do—draw

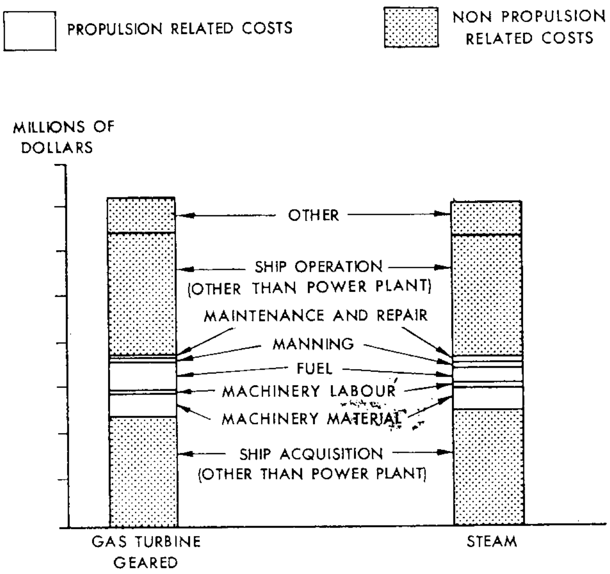

FIG. 3—SINGLE SHIP LIFE-CYCLE COST BREAKDOWN SHOWING MAJOR COST COMPONENTS AFFECTED BY POWER PLANTS

from the plots the immediate conclusion that steam propulsion is the cheapest and so is the clear winner. Such a conclusion is ill advised. The plots should be more appropriately interpreted as follows:

(*i*) Since the accuracy of many projected future operating costs and profiles is not known much more closely than ± 20 per cent, the cheapest and most cost-effective system cannot be identified.

(*ii*) The cost of owning ships of this type, as projected, is insensitive to the power plant and to the type of fuel.

(*iii*) Another method of analysis that is sensitive to the different types of propulsion systems is required for logical decision making; no decision can be made on the basis of FIGS. 2 and 3.

(*iv*) Since the future utilization, employment, productivity and deployment of most newly designed ships are vague and unpredictable, maximum flexibility to respond to changing future requirements—within reasonable cost constraints, of course—should be seriously considered in all new ship designs.

Further, we should bear in mind two assumptions that are often made but then overlooked in life-cycle analysis:

(*a*) Though steam, Diesel and gas-turbine propulsion systems are radically different concepts, we often assume that their effectiveness is equal, or adequate.

(*b*) The cost model used is only valid when comparing one system with a close variant of the same system, because the cost consequences of various but different operational scenarios are usually not considered, i.e., cost and time to repair a random failure, cost and time to prepare the ship to go into, or be removed from, the Reserve Fleet, etc.

The following can be deduced from FIG. 4, which grossly summarizes for combatant ships the computed cost of ownership over a 20-year life cycle:

(*i*) Ownership cost is not greatly influenced by the cost of fuel, whether it is NSFO (Naval Special Fuel Oil) or Diesel oil, or is free.

(*ii*) Fuel can have a substantial impact on the cost/effectiveness of a combatant ship only by influencing effectiveness, not cost.

(*iii*) The more intricate and sophisticated a combatant ship with normal displacement becomes, the weaker is the impact of fuel cost.

(*iv*) Life-cycle studies of gas-turbine and other propulsion concepts for combatant ships should hit hard not at fuel cost, but at repair and personnel costs, improved world-wide machinery logistics support, time off the line to make repairs, and overall ship effectiveness.

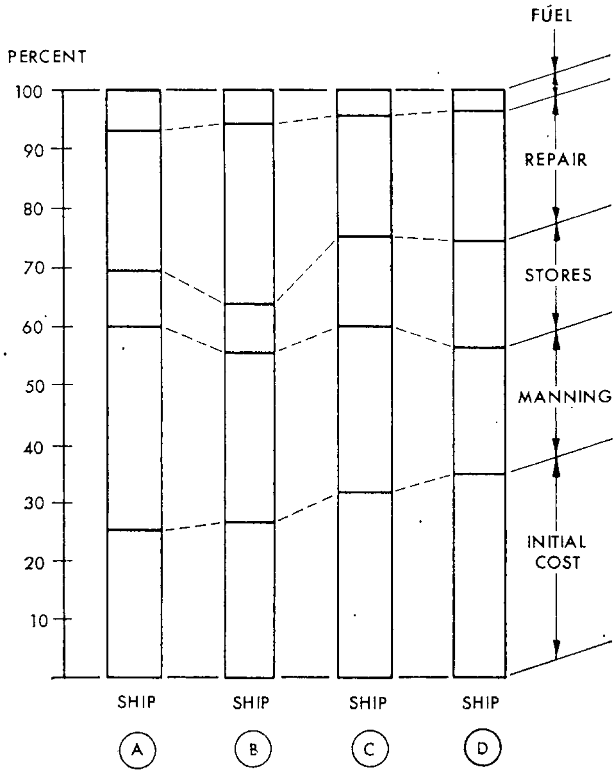

FIG. 4—LIFE-CYCLE COST (20 YEARS)

Weakness of Analyses

The weakness of all the examples discussed reduces down to two major oversights:

(*i*) Failure to appreciate that changing the propulsion system has a treacherous way of changing not only the whole ship system, but the support system and ship utilization—even how mankind can utilize ships.

(*ii*) The evaluation of new concepts has been made in terms of old environments, not taking into account new environments that are most likely to be characteristic of the future.

SUGGESTED APPROACH

Cost

Chances are that it would not be profitable to spend much time expounding how to compute the cost aspect of the cost/effectiveness equation, for that has already received a considerable amount of attention. This is not to imply that there is unanimity of agreement on how cost should be computed or that our techniques cannot be improved. With the passing of each day, estimating will grow more accurate.

History indicates that life-cycle costs are often grossly under-estimated and that cost estimates are frequently misused. Instead of being employed to determine whether the cost of ownership of various systems can be tolerated, they are often used to select one system over others, even though the differences in cost of the alternatives are slight and many times undefinable. The accuracy of life-cycle costs, at best, will always leave a lot to be desired, and without extensive deliberation on effectiveness issues can be very misleading. The cost of ship down time has usually been under-estimated, basically from not allowing for down time. The cost of ship damage is seldom in the equation. It is possible, through design, to have ships that should have marked differences in both random-failure down time and ship-damage down time, so why not reflect these differences in the analyses? Usually crew costs are greatly under-estimated.

The U.S. non-defense reserve fleet is shown in FIG. 5. No doubt there were long debates by sharp naval architects, marine engineers and designers over various machinery systems in regard to the economics of fuel expected to be consumed over a 20- to 30-year ship life expectancy. History again clearly shows us that, in some 1600 ships over a span of 22 years (35 000 ship years), we engineers misled ourselves and many others by computing fuel economics

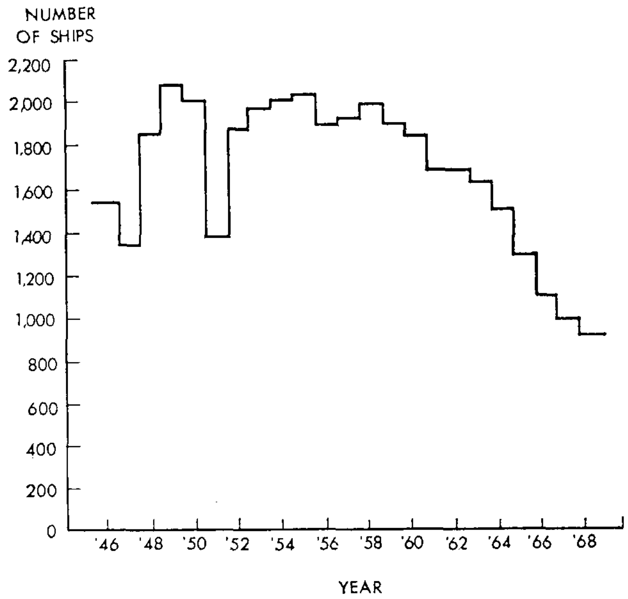

FIG. 5—U.S. NON-OPERATING MERCHANT SHIPS

at something like 1 pound per shaft-horsepower-hour for an extended period when it should have been zero. Over a 30-year ship life, we ground in at least a ninefold error.

Effectiveness

As great as the deficiency in cost estimating may seem to be, there have been far greater and far more disastrous errors in assessing effectiveness, or in determining how a change in power plants affects the whole ship system and how different power plants change the utility of ships to mankind.

EFFECTIVENESS ELEMENTS

Elements used in effectiveness modelling must enable an assessment of the influence of various machinery systems in changing the effectiveness of the total ship system in both the near and far terms. They should be elements that will measure the potential differences in the total ship's performance that are in excess of yesteryear's minimum requirements.

The assessment of total potential effectiveness is very important for at least two reasons. First, some elements of effectiveness may never be realized solely because a given ship design does not incorporate features to exploit them. Second, a ship has a relatively long life span and thus will experience new environments and changes in utilization that can be predicted with a fair degree of certainty today. Elements used in effectiveness modelling should be selected and tailored in the following ways:

(*i*) Elements should represent significant factors which improve, not reduce, total ship system performance over minimum requirements.

(*ii*) Elements should be tailored for each machinery system under consideration.

(*iii*) Elements should be evaluated in terms of a reasonable future environment, not necessarily today's, and definitely not past ones.

Effectiveness of Marine Propulsion from Aircraft Derivatives

For a considerable period of time, compact aircraft-derivative gas-turbine modules modified for ship propulsion or ship service duty have appeared to offer the potential of signficantly improving the effectiveness of commercial and military ships. Some of the more obvious advantages of such a propulsion system in relation to present systems could be the following machinery effectiveness elements:

Small Prime-Mover Family

Aircraft-type prime movers have the distinct potential of meeting all power requirements, both ship service and main propulsion, on all commercial-type ships (small or large cargo ships, passenger ships, tugboats, even hydrofoils) with no more than five or six discrete power sizes. This same family would have the potential of powering most naval ships. One can see living proof of this potential in the 200-ton Canadian hydrofoil, the Canadian and Danish destroyer programmes, the U.S. Coast Guard Cutter programmes, and the MSTS 24 000-ton cargo ship, USNS *Admiral Callaghan*, which are propelled with practically the same power module—just one module of a family of five or six.

This impressive degree of standardization has evolved more or less by accident, and concerted engineering talent devoted to the problem could bring about startling rewards.

Investment Required to Advance and Exploit Technology

The aircraft industry is highly competitive. Vast sums of money are continually invested to push aircraft-engine technology and the production of new aircraft engines to new frontiers. The limits of aircraft-engine technology and performance are expanding at a staggering pace. It is not uncommon to find that a fully mature new aircraft engine represents an investment of $200 or $300 million in research and development and that the new versions burn 25 per cent less fuel than their predecessors, produce double their power, and occupy less space.

Figuratively, we might consider the aircraft industry a rich uncle and the ship industry a poor relative. In order to ride the coat-tails of rich uncle, we need only make modest investments, establish known ship requirements that are compatible with those of aircraft, learn how to adapt aircraft power plants to the marine environment and develop relevant techniques, and, finally, develop the auxiliary components peculiar to marine installations.

It is difficult to imagine any other field of ongoing machinery development that offers a greater return for ship machinery.

Power Availability

Shipboard power plants, which are aircraft derivatives, offer a tremendous potential for improving power-plant availability. A ship can be designed so that a defective power module could be replaced within a few hours by six or seven men while the ship is receiving power from other operative units. Thus, for such maintenance or change-out activities, shipyard availability would not be necessary. The requirement for shipyard availability cuts rapidly into a ship's at-sea time and triggers high support costs. Reducing the frequency and duration of shipyard use would result in more active up time for the ship, as well as other economies.

It is conceivable that, within the near future, ships powered with aircraft-type machinery need never have machinery overhauled in shipyards. This could be accomplished by unit replacement while the ship is on the line. Such a procedure would be the equivalent of overhauling the machinery in a steam plant, including all ancillary equipment from the steam turbine back through the boilers. The equivalent would include overhauling at least:

(*a*) Main and auxiliary condensers
(*b*) Main and auxiliary condensate pumps
(*c*) Main and auxiliary condenser circulating pumps
(*d*) Main and auxiliary air ejectors
(*e*) Deaerating feed tanks
(*f*) Main feed pumps and feed pump boosters
(*g*) Force-draft blowers
(*h*) Fuel oil heaters

(*j*) Steam boilers
(*k*) Reserve feed water tankage
(*l*) Large evaporator capacity for reserve feed water
(*m*) Steam gland exhausters
(*n*) Several tons of piping and fittings.

Some people discount this effectiveness element on the grounds that ships require periodic shipyard availability for other maintenance purposes. This response overlooks a real fact of life: the more complex ships have been requiring longer overhaul and upkeep periods. This is due, in the main, to limitations in crane service and other yard facilities that can be brought to bear on a given ship during repair. In short, during an overhaul, the space in which men and services must be brought to the job becomes congested.

The physical removal from the ship of a substantial on-board work load would shorten the time of yard availability. If all systems could be removed for overhaul while the ships continue operating, shipyard availabilities would be just about eliminated.

Time to Recover from Random Machinery Failures

This is an important effectiveness element to consider, as a marked improvement over current systems is attainable with aircraft-type gas turbines. It takes days, or even weeks, to recover from some failures that may occur in steam or Diesel systems. The gas turbine has the potential of recovering in hours no matter what the failure may be. Failures of crankshaft, steam boiler, condenser, high-pressure steam manifold, and the like, are not quickly repaired even when spares are at hand. Time to recover is highly dependent on the availability of material and facilities, as well as a sizable skilled work force.

The cost of such failures is far greater than the cost of effecting repairs, plus normal ship demurrage and loss of revenue. Whenever a ship falters on a scheduled run, labour and production ashore are affected on each leg of a ship's run all the way from the place where the cargo shipped was manufactured to the place of delivery to the ultimate consumer.

Excessive warehousing and stockpiling have been built into our current system as a hedge against poor ship schedules. The fact that steam-propelled ships were able to reduce this hedge from that required by the sailing ship had no small influence in closing out the era of sails. In more recent times, air freight is becoming more attractive for the same reason.

The gas-turbine-powered ship should be able to maintain a much tighter guaranteed operating schedule.

The advantage of rapid recovery of combatant ships from random machinery failures is obvious.

Suitability of ship Power Plants for Other Applications

To a limited degree, Diesel prime movers have been able to exploit this performance element. As a result, the production base of some Diesel engine models has been greater than just the quantity representing ship requirements.

The gas turbine can exploit this performance element to a much greater degree, primarily because the light weight and compactness of gas turbines make them economical to be removed from ships, replaced and/or transplanted to a vast number of other applications. Gas-turbine power plants can thus be continually shifted from aircraft to peak-load power generation, to shipboard use, to pipeline pumpers, to world-wide spare-parts support systems, and to other applications, so as to make best use of old, current and advanced engines, depending on the priority of the use and operational requirements.

Such flexibility will make it possible to salvage power plants in ships scheduled to be scrapped for further use, as well as to reduce the capital investment tied up in ships that are in reserve fleets or not in active use.

Ability to Upgrade Machinery Systems During Ship's Life

This element of effectiveness has several possible aspects. One is the current necessity of maintaining large worldwide inventories of spare parts that are technically obsolete but are essential to keep old ships in operation. This need not be the case with respect to machinery systems that can be economically modernized during a ship's life.

For whatever reason—uneconomic repair, need for more horsepower, need for greater endurance—ships whose obsolete power plants can be replaced with more modern ones could be supported with smaller spare-parts inventories.

Further, there need not be any scrapping of machinery spares with the scrapping of the last antique ship, because, beyond a certain power vintage, only modern spares need be stocked. To achieve this element of effectiveness—that is, to make it economical and desirable to upgrade machinery systems during a ship's life—we are defining a system that must be compact, lightweight, simple, not built into a ship, and capable of tremendous future growth; above all, it must exploit a plug-in concept much like that of a light bulb.

Other Performance Elements

Without going into a detailed discussion, other performance elements could be:

(*a*) Reduced spare-parts inventories to support all ships
(*b*) Utilization of existing non-ship supply, support and overhaul facilities
(*c*) Central stocking and rapid world-wide aerial delivery of complete power plants and required logistic support
(*d*) Improved performance of ships required to cycle through reserve fleet operations
(*e*) Improved automation of power plants
(*f*) Rapid response to power demands
(*g*) More flexibility in ship arrangements
(*h*) Reduced volume, space and weight devoted to ship machinery
(*j*) Improved compatibility to achieve total ship performance
(*k*) Improved power-plant growth potential.

And the list goes on.

SUMMARY

Few, if any of these differences appear in cost/effectiveness analyses of steam-, Diesel- and gas-turbine-powered ships, the reason being that they are difficult to quantify. *But they must not be ignored.*

QUALITATIVE AND QUANTITATIVE ANALYSIS

It is difficult to determine a rigorous quantitative approach to evolving a figure of merit for the systems effectiveness just discussed. There are, however, practical and meaningful qualitative approaches that can be powerful tools.

TABLE II

	Steam	Diesel	Gas Turbine	Relative Weighting Factor	Weighted Plus Factors		
					Steam	Diesel	Gas Turbine
1. Time to get underway with cold plant	2	10	10	4	8	40	40
2. Compatibility to achieve unmanned engine room as future alteration	2	10	10	9	18	90	90
3. Assurance to recover from random failures in minimum time	4	4	10	10	40	40	100
4. Compatibility to achieve 100% bridge control including light up and shut down	4	10	10	5	20	50	50
5. Assurance of rapid world-wide logistic support —large inventory of machinery, small No. of items requiring special order components air-transportable	4	4	9	9	36	36	81
6. Percentage of machinery spares that can be carried on board	5	5	9	9		45	81
7. Ability to maintain machinery without support of special availabilities	2	4	8	10	20	40	80
8. Time ease/cost and reliability to mothball and to activate	4	5	10	8	32	40	80
9. Reduced capital while in reserve fleet	5	5	9	10	50	50	90
10. Compatibility to up-grade machinery during mid-life—increase power, increase ship speed, increase endurance, decrease manning	5	5	10	5	25	25	50
11. System simplicity	5	8	9	5	25	40	45
				Total	319	496	787

One approach would be to list the plus effectiveness features for each propulsion system that exceeds minimum requirements in tabular form, as shown in TABLE II. A refinement would be to introduce an arbitrary numerical weighting system by using a scale of zero to 10. If the system under consideration has the greatest, or maximum, potential of realizing a plus performance feature, a rating of 10 would be assigned; if no potential exists, it would be rated zero.

A meaningful analysis of this type could begin to highlight significant performance differences between the various propulsion systems being considered. An additional refinement would be to incorporate the relative weighting factor of each element in relation to each other element under consideration. Factors of 10 to zero could be used; 10 would be the highest priority, and zero would mean that the performance plus element is not worth considering for the scenario under study or for future missions of the ship. The zero relative weighting factor would give one a second chance to discard an element that may have been introduced but, after further study, is determined to be undesirable.

TABLE II is a partial example of such an analysis for a high-speed roll-on/roll-off cargo carrier.

The results of this analysis could be pursued further. Let us assume that, by earlier analysis, it was determined that steam-, Diesel- and gas-turbine-powered ship designs should be investigated in depth. We now could assume that the effectiveness of these designs meets a minimum acceptable value. We could also assume that the total system effectiveness of the best design, including all effectiveness pluses, would be 100. Acceptable minimum performance would be something less, say, 70. Then, for the example under consideration, the total system effectiveness of the three systems would be:

1. Steam 82
2. Diesel 89
3. Gas turbine 100

Whether minimum performance is 70 or some other figure is a matter of judgment. The more rigorous our analyses and the better our insight into future economic trends, as well as future missions and deployments in which the ship will be involved, the smaller should be the allowance for performance pluses. On the other hand, excessive allowance for performance pluses need be addressed seldom, if ever, since this indicates serious deficiencies in defining the basic minimum requirements. It should be recognized that, once a qualitative assessment is undertaken, careful judgment must be exercised at every step.

The problem here is to develop a more rational approach to evaluating the cost/effectiveness equation. As poor as our life-cycle cost procedures are, we have always attempted to arrive at different life-cycle costs for each system proposed or studied. Seldom has there been a simultaneous assessment of the effectiveness of each system considered.

CONCLUSION

No two systems cost the same, and no two systems have the same effectiveness. Thus, to assess the relative cost/effectiveness of two competing systems, an assessment must be made of cost and another of effectiveness. Any cost/effectiveness analysis that fails to recognize that both elements are simultaneous variables must be very suspect.

New propulsion concepts seldom become attractive if evaluated wholly on the basis of criteria used to evaluate older concepts. Usually, to be attractive, the new concepts must offer as a minimum the potential for realizing several worthwhile performance factors of which the older systems are incapable.

Especially for long-life systems like ships, a tremendous effort must be made to frame the sense, at least, of future environments. We engineers can do a better job of shining a light on this future environment than the operators, but for some reason we have been hesitant to assume this role.

Far too little use is being made of qualitative analysis by the marine engineering profession. Engineers like to be associated with more concrete analyses such as 'probability theory,' etc. But innovative advances frequently cannot be assessed by quantitative analysis, because the innovation often sets the stage for a revolution and almost always generates a problem far too complex for existing quantitative approaches. Qualitative analysis could serve us well if we would accept and use it.

Finally, we engineers, who are in the best position to develop logical studies aimed at plotting our course, should do so—and not allow the poets, or lawyers, or politicians to steal our thunder.