SIZE, TYPE, AND SPEED OF SHIPS IN THE FUTURE

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INTRODUCTION

Owners and builders of merchant ships generally view radical new ship designs with a certain amount of cautious reservation. These people frequently realize from past experience the expenses which accompany the development and application of new ideas in the field of naval architecture.

In serving naval interests, however, the situation is different. Military considerations and economic and psychological factors all play important roles. The seemingly uneconomical increases in the speed and power of tankers, and the development of nuclear propelled submarines, hydrofoil boats, and hovercraft are all projects which have been strongly stimulated by naval interests.

A speed increase of 18 to 20 knots is no longer being considered by the designers of high speed boats such as hovercraft. Indeed, speeds of 40, 60 and even 100 knots are now being discussed. Designers of these new and progressive ship types are being confronted with questions such as: How can we develop a 100-knot ship for operation on, beneath, or immediately above the surface of the water? or What is the maximum shaft power which we can install on one shaft? One might perhaps just as easily ask: What is the maximum length of a ship? The answer to this last question could, of course, be given as all the way from New York to Amsterdam, since optimum performance at sea has here been assured and guaranteed.

In all seriousness, however, the author hopes to convey that it can be nothing short of refreshing for the shipbuilder who is firmly established in mercantile construction to take an active part in and even take the very necessary initiative in the field of naval development.

If we but look carefully at the developments of the past 20 years, the following facts become unmistakably clear:

The design of ships, which has heretofore been primarily empirical in character, is clearly becoming more and more scientific and fundamental in nature. Increases in ship speeds and ship dimensions and the development of new and different types of propulsion systems have required ever more theoretical treatment.

Prior to 1940, the maximum shaft power which could be installed per shaft in merchant ships was in the order of 10,000 metric horsepower. At the present moment 16,000 shaft horsepower is the normal case, and frequently 20,000-shp installations per shaft are encountered. Ship speed for tankers increased at the same time from 10 to approximately 17 knots.

The development of push boats has led to a large application of this type of transportation on inland waterways.

The rising importance of the hydrofoil boat is undeniable. The application of the hovercraft principle to marine vessels at the present time offers unknown prospects.

These imposing developments have induced several investigators to make speculative examinations of future possibilities. Gabrielli, Von Karman, Davidson, and others have kept themselves busy with more or less philosophical considerations in the field of transportation.

Representative of their ideas is the relationship between the dimensionless constant $P/V_S\Delta$ and the speed coefficient $V_S/\Delta^{1/6}$ for various means of transportation. The various ranges of this relationship are clearly presented in Fig. 1 for displacement ships, submarines, hydrofoil boats, hovercraft, and so forth.

The philosophy behind this presentation in Fig. 1 is that there will always be a requirement for new developments in a vehicle whose characteristics permit it to be placed in a blank area of the plot. In accordance with this thought process both hydrofoil boats and hovercraft are always meaningful. They may be expected to fulfill already existing and yet to be established requirements.

Supertankers

Supertankers form a type of ship which is indeed one of the most spectacular examples of increases in displacement and speed of ships. In Figs. 2a, 2b and 2c, several characteristic properties of supertankers are given on the basis of cargo carrying capacity or deadweight tonnage. The various points on these plots are derived from model tests conducted at NSMB; the curves presented are faired lines drawn through these points as accurately as possible, without any correlation analysis. Noteworthy in Figs. 2 are the following:

The increase in the beam-draft ratio, B/T, with increase in deadweight tonnage. The limitation in draft to a maximum of about 10 meters in connection with the expected depth of water in harbors thus plays an important role.

The increase in the block coefficient δ_{11} with larger deadweight tonnages is alarming by comparison with standards which still were valid 15 years ago.

Finally, the power required for ships' speeds between 15 and 17 knots and deadweight tonnages above 50,000 metric tons deserves consideration. Considered from this point of view, the development of diesel engines of 20,000 to 22,000 hp in one 10- or 12-cylinder installation is not amazing.

The large power per shaft in these extremely full ships has caused serious vibration phenomena and has led to damage. Experimental research has shown that extreme afterbodies, for the obtaining of a uniform circumferential velocity field in way of the propeller, and propellers other than the conventional screw must be taken into consideration.

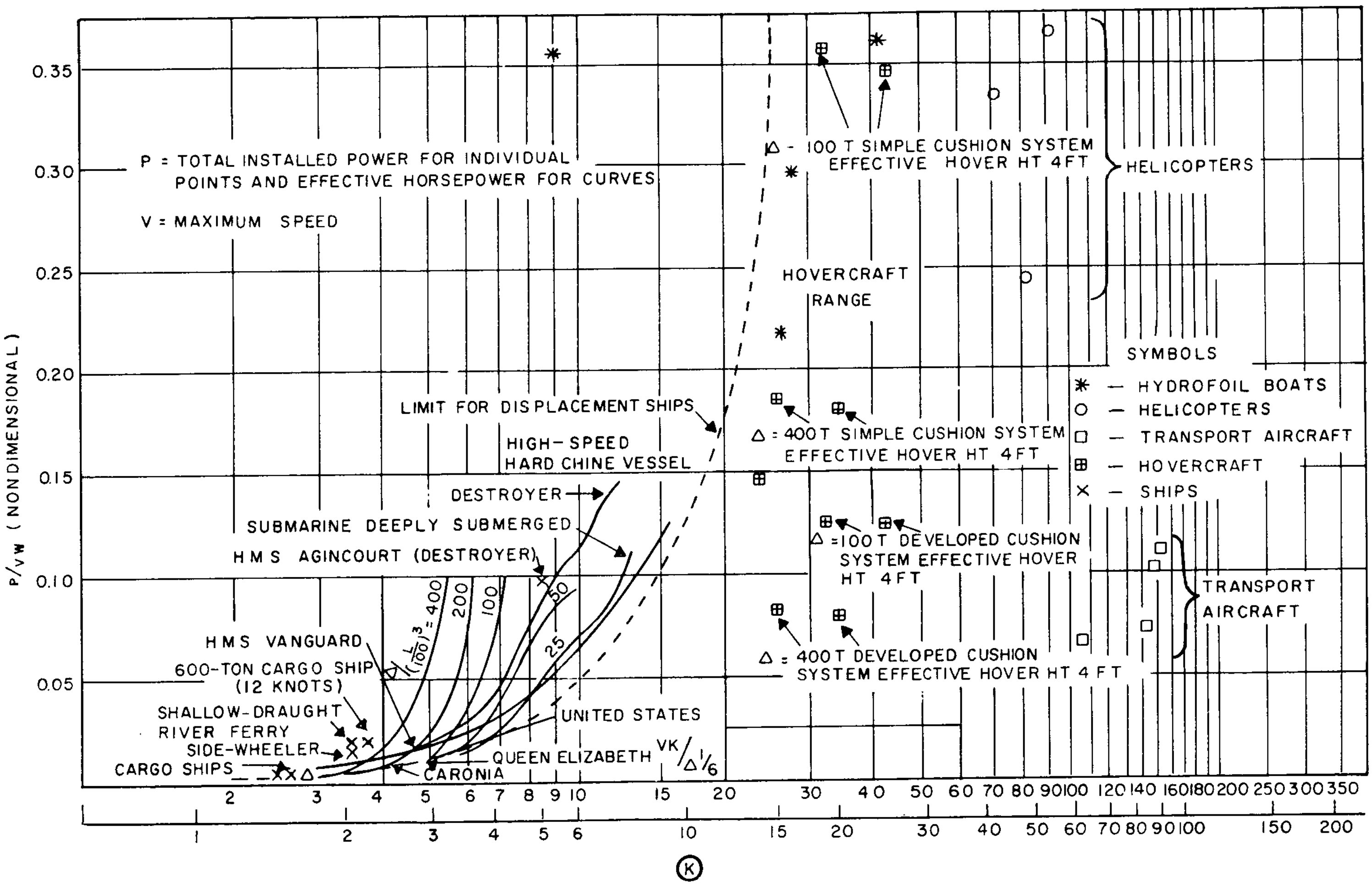

Fig. 1. Comparison between specific resistances of ships, boats, hovercraft, and aircraft (from Crewe and Eggington)

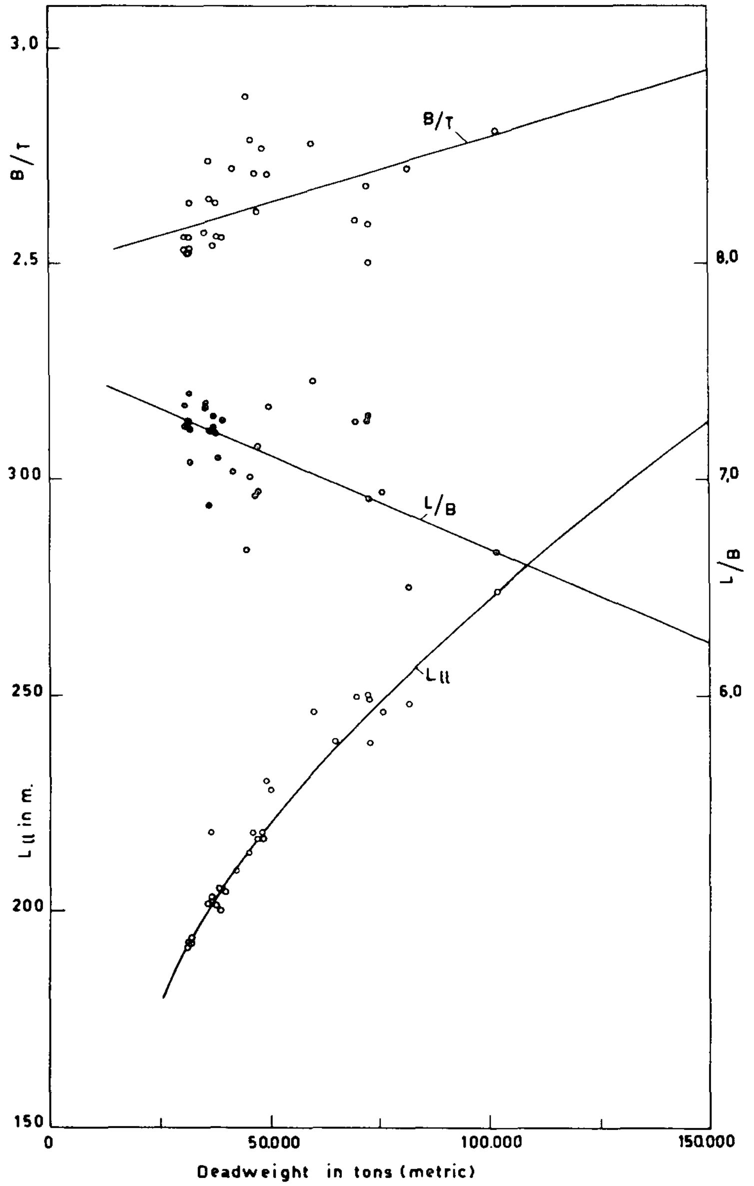

Fig. 2(a) Characteristic properties of supertankers

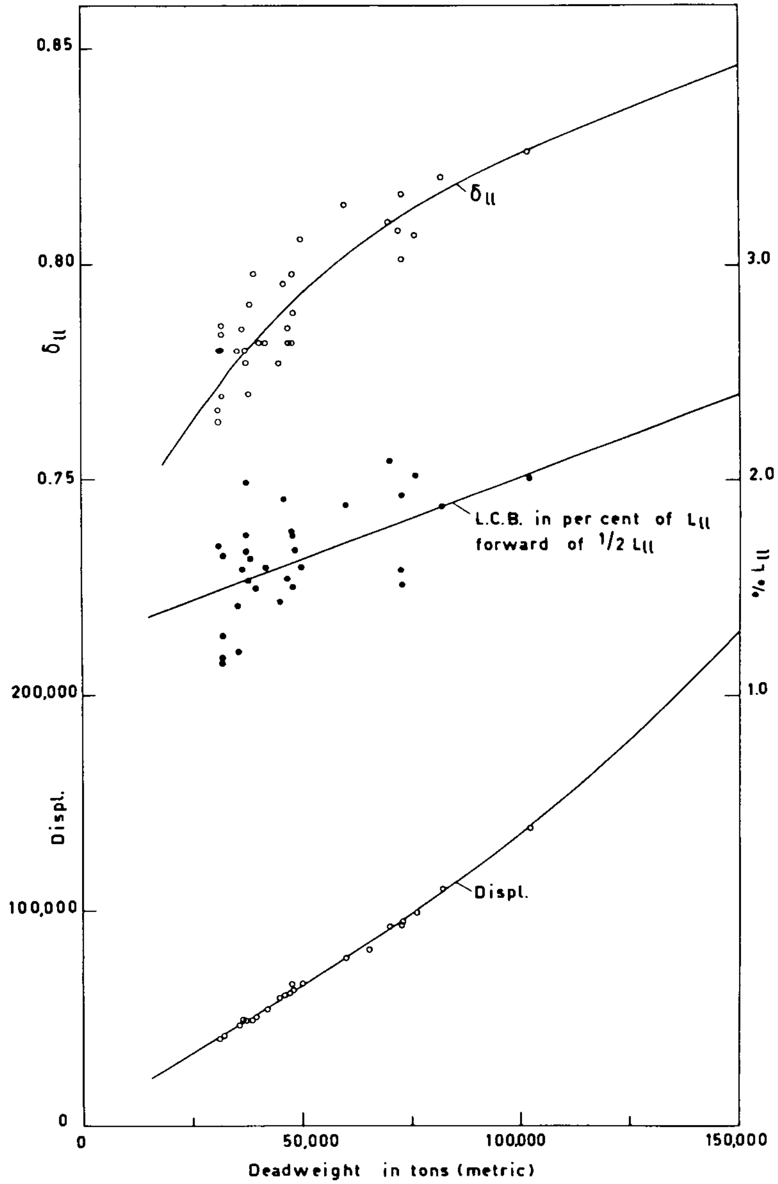

Fig. 2(b) Characteristic properties of supertankers

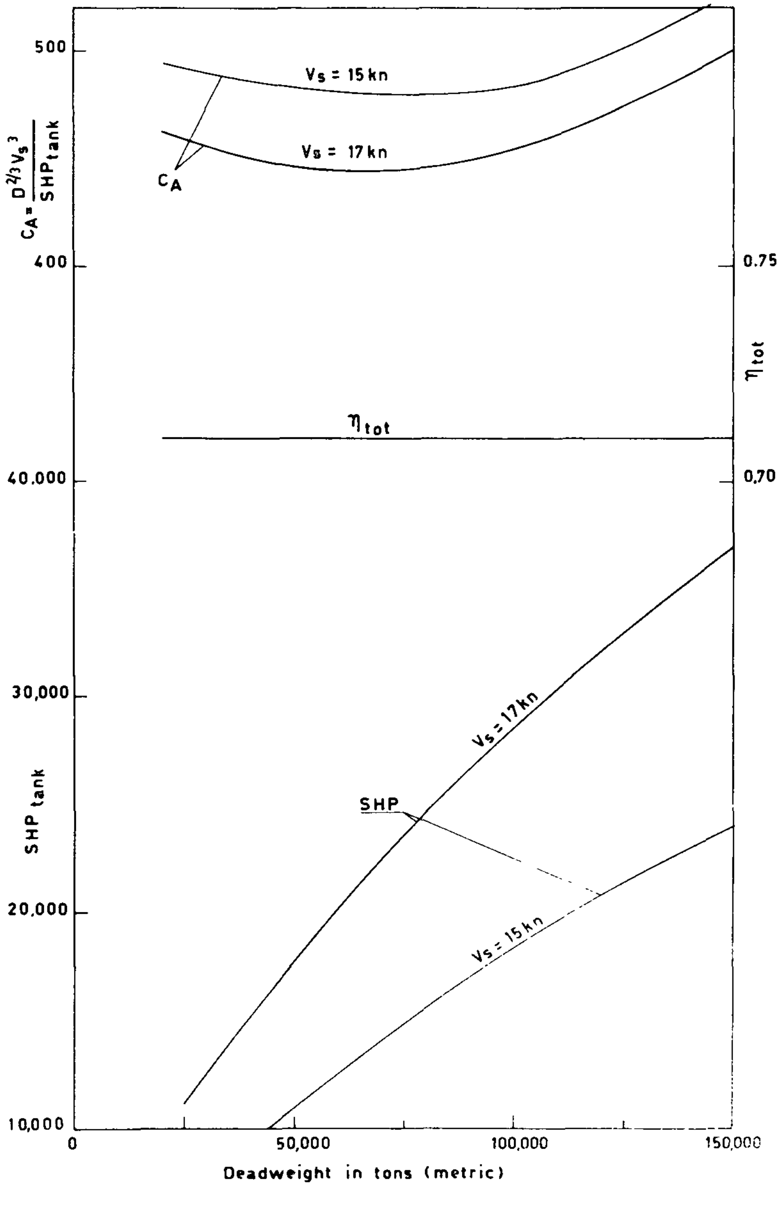

Fig. 2(c) Characteristic properties of supertankers

The 2-percent saving in shaft horsepower obtainable with the cigar-shaped Hogner afterbody provided with a complete ring nozzle propeller system becomes highly significant when considered together with the 25-percent reduction in propeller diameter obtainable over that of a conventional screw, and with the notably reduced vibration and cavitation characteristics (Fig. 3 and Table 1).

Table 1
Effect of Afterbody Shape on Propulsion
Results of Resistance and Self-Propulsion Tests on a Model of a 39,000-ton Tanker
(loaded condition; speed, 16 knots; 16,000 shp)

Afterbody	Screw	Number of Blades	Total resistance (percentages—afterbody I = 100)	DHP (percentages—afterbody I = 100)	Propulsive Coefficient
I (moderately U-shaped)	A	4	100	100	0.74
II (extremely V-shaped)	A	4	97	106	0.67
III (extremely U-shaped)	A	4	103	102	0.75
IV (Hogner form)	C	4	108	103	0.77
V (III + nozzle)	D	4	103	101	0.75
VII (twin screw)	G	3	100	105	0.70
VIII (Hogner + nozzle)	D	4	108	98	0.81

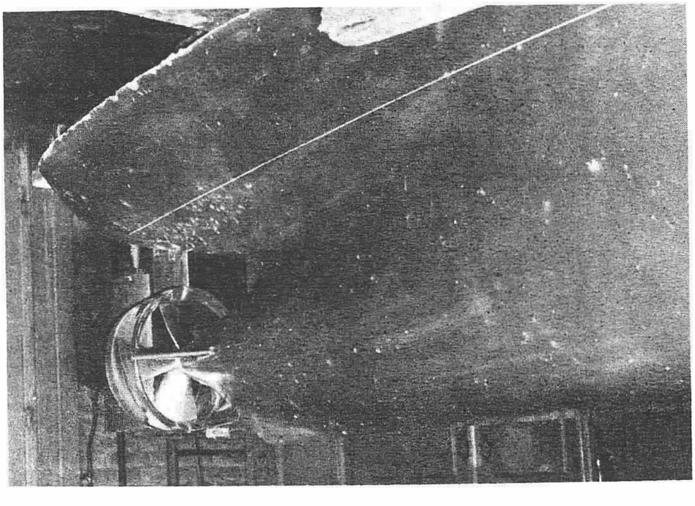

Fig. 3. Tanker model with cigar-shaped afterbody and a propeller operating in a nozzle ring

Another question which must be asked for supertankers is: At which speeds and deadweight tonnages does the submarine tanker, through application of nuclear propulsion, become competitive with its surface counterpart.

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In general, it is to be expected that, for a cargo carrying capacity of 20,000 dwt and a speed larger than 20 to 25 knots, the submarine tanker will have a distinct advantage over the conventional tanker. The Electric Boat Division of General Dynamics Corporation has made, under contract to the Maritime Administration, a study of nuclear propelled submarine tankers for mercantile application. Neither military nor economic factors were considered in this study, which embraces 27 different designs.

The 27 designs were carried out for ship speeds of 20, 30, and 40 knots, cargo carrying capacities of 20,000, 30,000, and 40,000 dwt, and for three types of cross section, namely, rectangular, limited in draft; rectangular, unlimited in draft; and circular. The designs restricted in draft were made suitable for harbor depths of water of about 11 meters.

Of these 27 designs, two types of submarine tankers appear worthy of further development: the most conservative, and the largest and fastest.

The Most Conservative

The most conservative design would be one of rectangular cross section, limited in draft, for which the following numerical data would apply:

Cargo deadweight	21,189 tons
Speed	20 knots
Surface displacement	38,791 tons
Submerged displacement	42,671 tons
Loaded draft	35 feet
Length	583 feet
Beam	80 feet
Depth	40 feet
Total power required	35,000 shp
Number of screws	1

The Largest and Fastest

The following design is currently considered as an upper limit in ship speed and cargo carrying capacity because of the present state of power plant technology:

Cargo deadweight	41,565 tons
Speed	37 knots
Circular cross section	
Maximum diameter	80 feet
Surface displacement	91,903 tons
Submerged displacement	101,000 tons
Loaded draft*	67 feet
Length	936 feet
Total power required	240,000 shp
Number of screws	4

*Made possible by the addition of a parallel middlebody.

Noteworthy here is that Electric Boat Division currently considers 60,000 shp the maximum which can be installed per shaft.

TYPES OF PROPELLERS

After the numerical data mentioned in the preceeding section, a discussion of propulsion seems desirable.

A frequently used method of expressing the characteristics of a propeller type is the relationship between $B_P - \delta$ and η_p for optimum propeller diameter. These are defined as:

the design coefficient:

$$B_P = \frac{N\sqrt{P}}{V_a 2.5} :: K_Q^{1/2} . J^{-2 1/2}$$

the diameter coefficient:

$$\delta = \frac{ND}{V_a} :: J^{-1} .$$

This optimum relationship is given in Fig. 4 for various types of propellers, namely, (1) supercavitating propellers of the type TMB 3-50, (2) wide-blade propellers of the type Gawn 3-110, (3) propellers of the type Wageningen B 4-40, (4) propeller with nozzle rings of the type K 4-55, with a length-diameter ratio of 1/2. The range of profitable application of each type of propeller is given on the basis of B_p. The considerable difference between the optimum diameters of supercavitating and conventional screws and screws in nozzle rings is noteworthy.

Since an evaluation of types of propellers on the basis of $B_p - \delta$ can be troublesome for those who do not work with this type of data every day, a more convenient and instructive method of presentation is given in Figs. 5(a), 5(b), and 5(c) illustrating the general tendencies of the propellers discussed.

In Fig. 5(a), the power-rpm relationship is given for various speeds and diameters, as derived from the optimum relationship presented in Fig. 4, for supercavitating propellers. The cavitation thresholds, according to Tachmindji and Morgan, and the limit of efficiency $B_p = 3$, beyond which this type of propeller would not be utilized, are given for 60, 80, and 100 knot speeds. Only one line of constant propeller diameter, i.e., $D = 1$ meter, is given. Other lines of constant diameter greater than 1 meter would appear to the right in the diagram. For reasonable application of a supercavitating screw with a diameter of 1 meter, a minimum speed of 54 knots is desirable.

In Fig. 5(b), the optimum $B_p - \delta$ relationship is presented in the same manner for conventional screws of the Wageningen B 4-40 type. If the limit of 60,000 shp given by Electric Boat is adhered to for installed shaft power, then this appears to lead to inadmissably large propeller diameters for speeds of 20 knots. For 40-knot speeds with 250 rpm there still appear to be possibilities.

The same data are presented in Fig. 5(c) for the K 4-55 series operating in ducted nozzles with a length-to-diameter ratio of 1/2. The superior properties of this type of propeller with respect to maximum installed power for relatively low speeds is clearly evident.

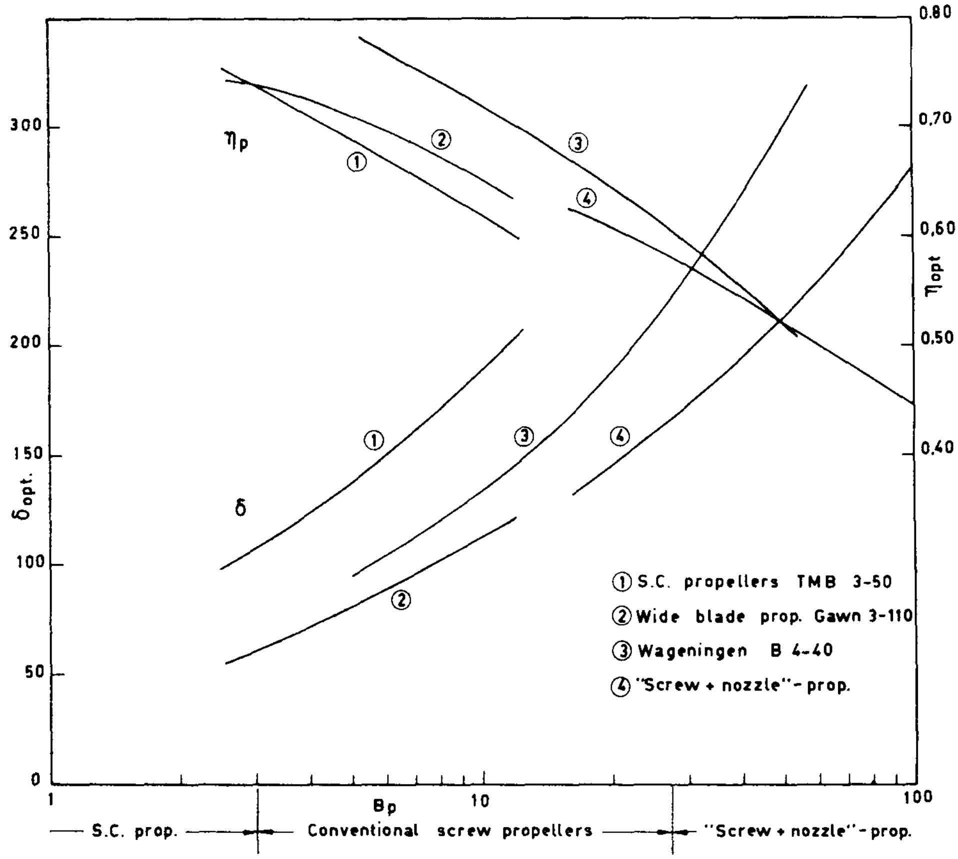

Fig. 4. Optimum relationship of B_p and δ for various types of propellers

Further investigations will have to indicate whether increasing the rpm of the ducted screw or of the supercavitating screw, or whether going to an entirely unknown field, ducted supercavitating propellers, is preferable.

GEMS AND HYDROFOIL BOATS

With the aid of Figs. 1 and 5(a) it is possible now to make estimates of size and shaft power for the design of high-speed craft such as GEMs (hovercraft) and hydrofoil boats.

Let us for the moment assume a reasonable and realistic power coefficient $P/V_S\Delta$ = 0.20. Then it follows from Fig. 5(a) that for an 80-knot hydrofoil boat with a 1-meter-diameter screw the maximum installed shaft power would be in the order of 4,000 shp, whence it follows that for a single screw craft a displacement of about 40 tons could be propelled. Therefore, for 80-knot speeds, hydrofoil boats will thus be limited, even with the installation of more screws, to cargo carrying capacities of from 40 to 120 tons.

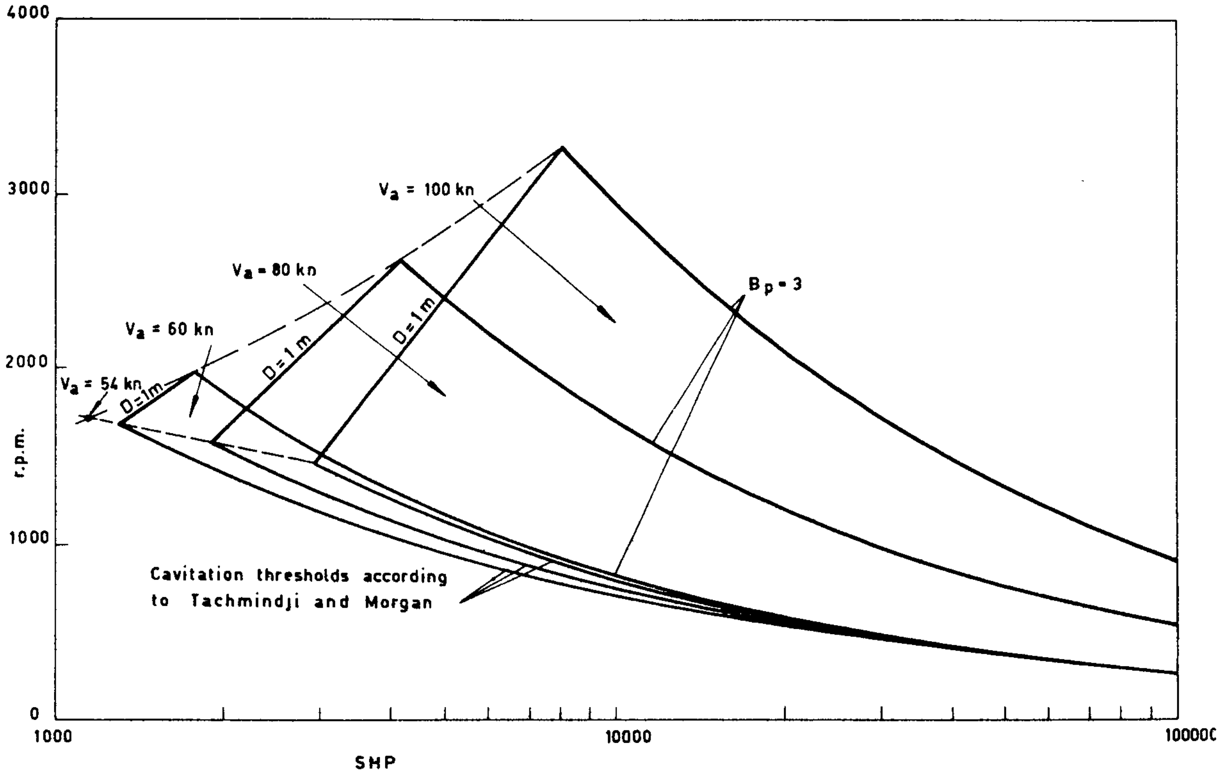

Fig. 5(a) Optimum power-rpm relationship for various speeds and diameters for supercavitating propellers

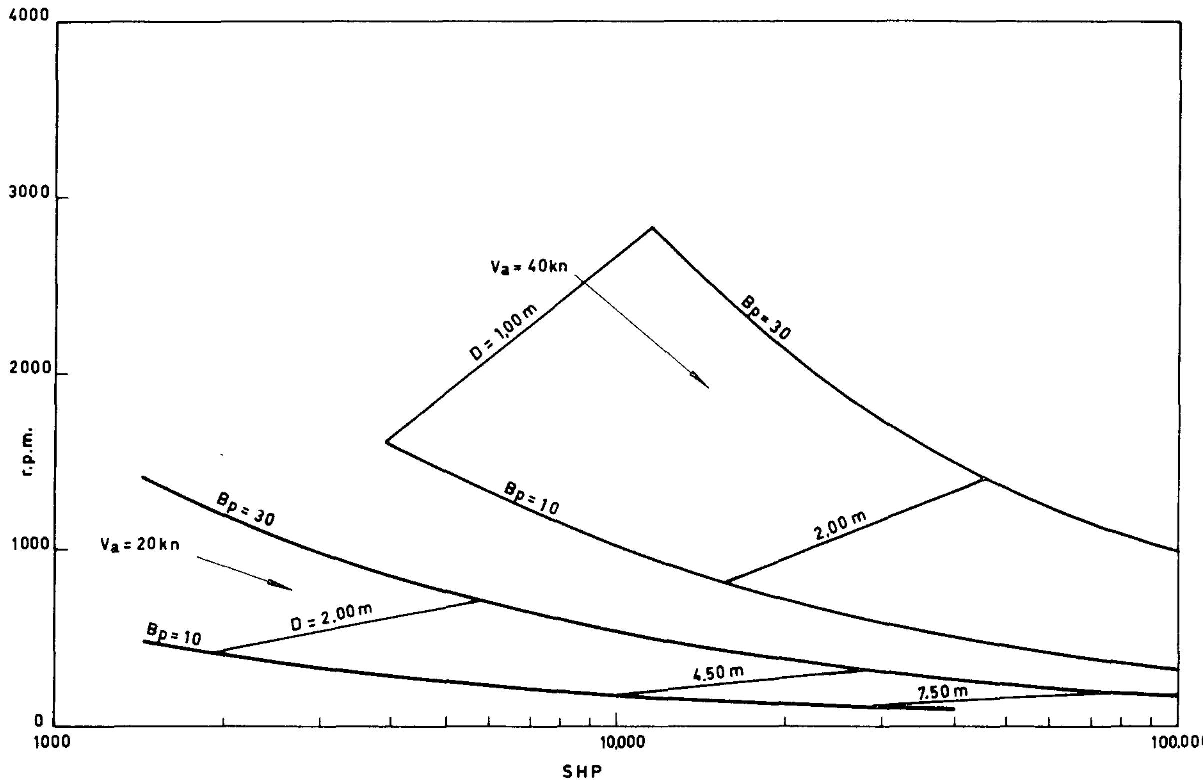

Fig. 5(b) Optimum power-rpm relationship for various speeds and diameters for conventional screw propellers

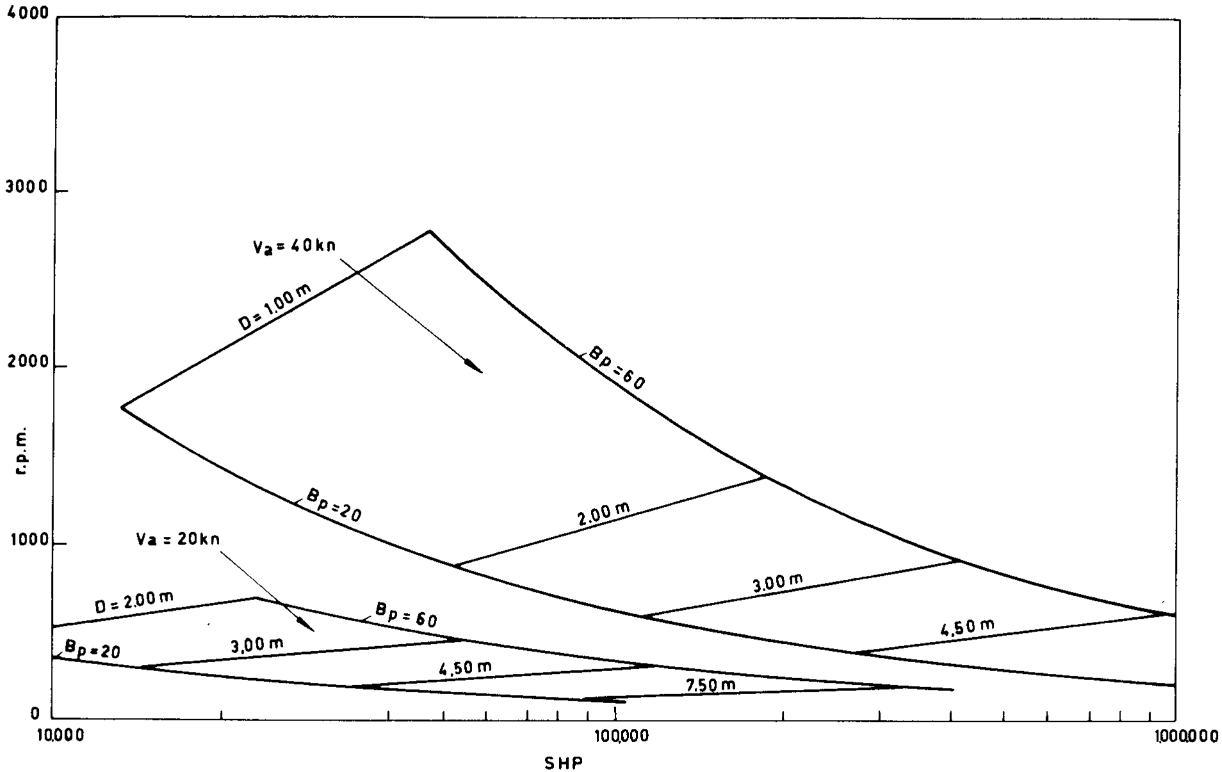

Fig. 5(c) Optimum power-rpm relationship for various speeds and diameters for "screw plus nozzle" propellers

If we continue this estimate of dimensions of prototypes in the same manner for a hovercraft, such as, for example, the 400-ton Crewe and Eggington project, then a power coefficient of $P/V_s\Delta = 0.15$ appears to have been chosen by the designers (P = 40,000 hp, V_s = 100 knots, Δ = 400 tons).

A rough weight distribution might appear as follows:

800 passengers plus 80 motor cars	160 tons
40,000-hp turbine, at 1.5 kg/hp*	60 tons
Fuel for 24 hours	130 tons
Hull	50 tons

With a diameter of 100 meters (air cushion pressure 50 kg/m^2) the weight of the structure becomes 5 kg/m^2. A further study of the lifting mechanisms and possible structural forms will be necessary to indicate how much the hull weight has to increase at the expense of the pay load.

If the supposition is made that 50 to 60 hp per ton of displacement are required for hovering, then from 20,000 to 24,000 hp will be required to maintain the air cushion. How much special provisions such as Weiland's labyrinth seal can improve this situation remains yet to be seen. We will therefore use 20,000 to 16,000 hp to give the 400-ton GEM a 100-knot speed. The important question which then presents itself for the case of a seaborne GEM is whether to use air or water propulsion. In Fig. 7 the optimum diameter and efficiency of supercavitating propellers in water and ducted propellers in air are compared against a basis of B_p. From this it appears that the diameter of the ducted propeller in air is approximately three times as great as that of a comparable supercavitating screw in water. The efficiency in air is approximately 40 percent lower than the efficiency in water.

Proceeding from an assumed propulsive efficiency of 0.75 in water and 0.45 in air, then for the available power of 20,000 hp and a speed of 100 knots, the following resistances per ton of displacement can be overcome:

55 kg/ton for water propulsion
33 kg/ton for air propulsion.

Whether it will be possible to choose the hull form and the operating height of the GEM so that these values can be reached, the future will have to show us. If we consider the water resistance negligible at these high speeds and assume the transverse sectional area of hovercraft and air cushion to be 600 m^2, then a resistance of 55 kg/ton in the case of water propulsion implies a drag coefficient of 0.23, which is comparable to that of an automobile.

In view of the large difference in efficiencies for water and air propulsion for a 100-knot GEM, water propulsion for a seaborne GEM should be considered. However, from these calculations for high speed GEMs one might be inclined to consider displacements, as predicted for hydrofoil boats, in the range from 40 to 120 tons to be more attractive.

Summarizing this introductory paper to this Symposium on High Performance Ships the following might be concluded.

*See Fig. 6.

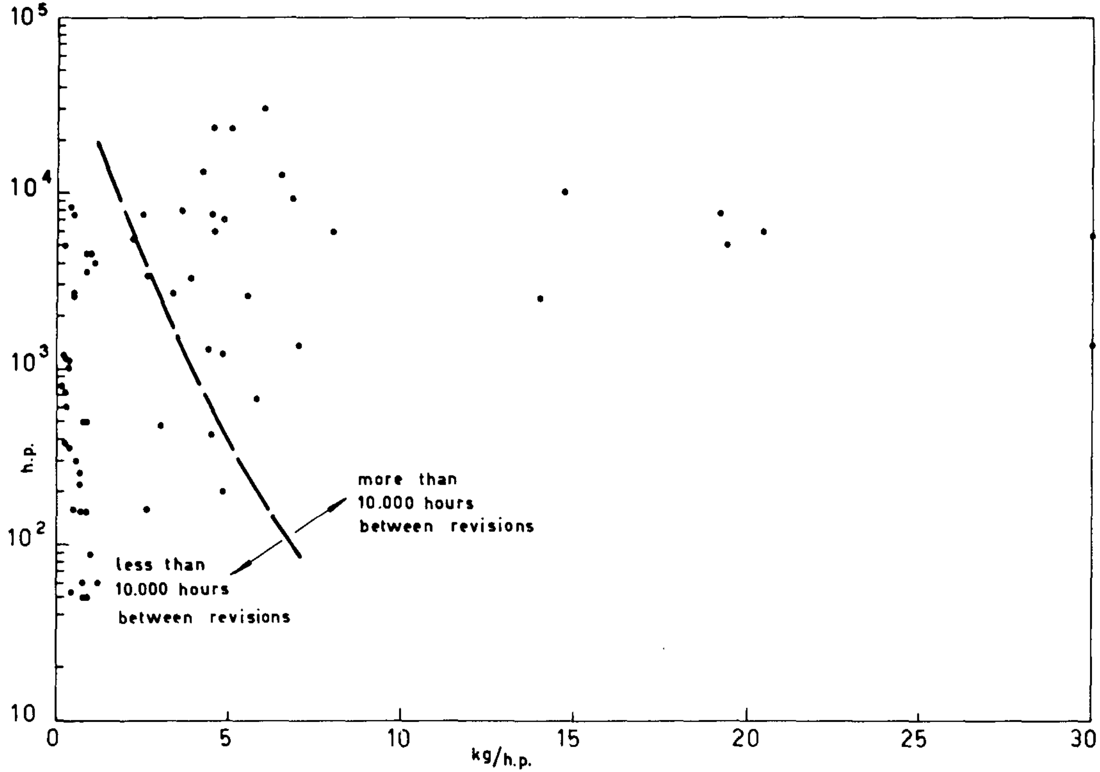

Fig. 6. Relationship of horsepower and specific weight for gas turbines for ships according to Diehl

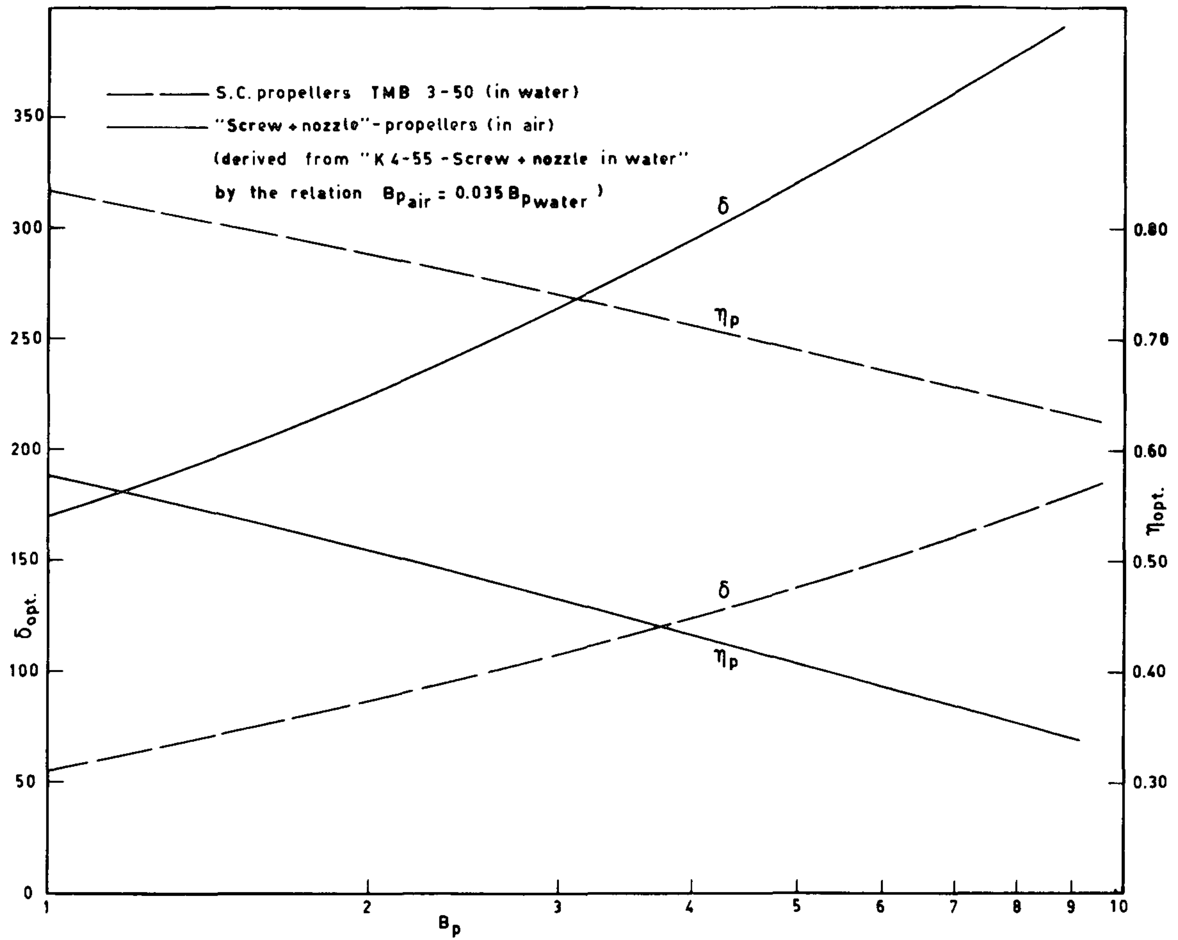

Fig. 7. Comparison of optimum diameter and efficiency of supercavitating screw propellers in water and "screw plus nozzle" propellers in air

For displacement ships (cargo), the increase in ship speed will stop between 20 and 25 knots. Above these speeds, the nuclear powered submarine will get its chance (future). The maximum draft will be limited to 10 to 11 m by harbors and docking facilities.

For submarine vessels (merchant ships), the limitations in horsepower per shaft and in available space for engines, especially athwartships, results in a maximum deadweight for submarine of 40,000 tons at a ship speed of 37 knots.

For hydrofoil boats, extremely high speeds such as 60-80 and 100 knots seem to be obtainable. The displacement of such high speed hydrofoil boats will be restricted to about 100 tons or less.

For GEMs, displacements greater than 100 tons combined with extremely high speeds (100 knots) lead to serious construction and propulsion difficulties. Propulsion in water seems to be attractive for a seaborne GEM.

DISCUSSION

R. N. Newton (Admiralty Experiment Works)

My remarks bear upon the papers presented by both Mr. Oakley and Dr. van Manen and concern those parts which deal with hydrofoil craft and hovercraft.

The considerable experience already acquired with hydrofoil craft leaves no doubt that one clear advantage of this type of craft over the orthodox displacement or planing types is the ability to maintain higher sustained speeds in a seaway. The same advantage, associated with higher speeds still, is being claimed for the more recent hovercraft or GEM.

One question which has yet to be resolved, however, is the extent to which this particular advantage applies; that is to say, it is necessary to qualify the words "in a seaway" to cast a true comparison with, say, the planing craft. The moral can be pointed, in humorous and yet serious vein in the present context, by this quotation from the writings of Hilaire Belloc:

"The water-beetle here shall teach
A sermon far beyond our reach;
He flabbergasts the human race
By gliding on the water's face
With ease, celerity and grace;
But if he ever stopped to think
Of how he did it, he would sink."

Whatever form the humanly conceived "water-beetle" may take, I submit the time has arrived to think seriously as to what state of sea would force it to stop and whether it would, in fact, then sink.

Assuming no breakdown of the engines to occur the craft can be forced to land on the sea from two principal causes:

1. Encountering waves of length and height in which it is not designed to operate. Statistical or spectrum analysis of the sea conditions in the operating area can provide much data to guide the design of the craft as regards lift, stability, control, and response. It can also provide an assessment of the probability of meeting isolated severe waves, but these cannot be predicted in the true meaning of the word.

2. Impact with such isolated severe waves, or even waves over which the craft is designed to operate if, for instance, a defect develops in the control system. In this connection, it should be noted that while models of the size normally associated with ship tank work can be used to measure the external forces, an assessment of the stresses induced by these forces is a matter for the structural designer. To relate the stresses measured in the full scale craft directly to those measured in a model, the latter would need to be of the order of 1/2 to 3/4 full size. So far as I am aware, no attempt to carry out investigations of this nature has yet been made, but presumably data available from flying-boat investigations would provide valuable guidance. It is significant also to add that the structure of hydrofoils and GEMs can hardly be regarded as "robust" in comparison with displacement or planing craft.

Having been forced to land in severe conditions from any such cause as 1 or 2, or due to engine failure, the question arises: Can the craft withstand the normal bending and shear forces imposed in a seaway, or the impactive forces due to slamming? The answer to this question also has yet to be resolved but in the absence of data on the subject, it is fairly sound to assume that present designs would need to be strengthened.

It is realized these observations may be regarded by some as being very pessimistic. At the same time, it is necessary to place the possibilities of high performance craft in their proper perspective in relation to what can already be achieved by displacement craft in unexpected severe weather conditions. The simple fact is that the planing or displacement craft can successfully sustain any sea condition, and proceed, even though the speed may be considerably reduced. Actually the reduction of speed is not so serious as is sometimes implied. Comparisons can be odious and figures can be exaggerated in the absence of factual data. Nevertheless it is my opinion that, for instance, size for size, the planing craft will still be capable of proceeding at nominally high speeds in conditions when the hydrofoil or the GEM is brought virtually to a standstill. In such conditions it is the planing craft which has an overwhelming advantage. Incidentally it must not be forgotten that a planing craft to carry 50 to 60 passengers at speeds exceeding 50 knots in calm water now offers no design or constructional difficulties.

The conclusion to be drawn from these few comments on this one aspect of the possibilities of high performance surface craft is that there exists a real need for investigations to determine more precisely their limitations in irregular sea conditions. This entails not only the advancement of theory and model experiment but also correlation with full scale results in similar conditions at sea—a long and arduous task following the lines of what is already being attempted for displacement craft. Costly and time consuming though the task may be it is quite essential to carry it out if any real comparison is to be made between the orthodox and unorthodox type of craft. If it is not carried out then the risk must always remain that a craft designed for some specified state of sea will meet more severe conditions and suffer serious damage or even loss, and as so often happens with new ventures, this could cause a serious setback, if not cessation, in development.

E. V. Lewis (Davidson Laboratory, Stevens Institute of Technology)

I wish first to compliment Mr. Oakley and the Bureau of Ships on their far-sighted viewpoint in considering such a wide range of possible vehicles for military use. The escort research ship in particular I am certain will be a significant milestone in naval ship design.

In its own way the modern supertanker considered by Dr. van Manen has been a truly spectacular development. In this connection it is rather surprising to find in Fig. 2(c) that the author expects to maintain a constant overall propulsive coefficient of about 71 percent in ships up to 150,000 tons deadweight. Presumably he is assuming single screw vessels, and I would expect a reduction in efficiency as size continues to increase. My reason for expecting this trend is that for geometrical similarity the propeller diameter should go up and rpm down in order to maintain good propulsive efficiency. However, in actual ships practical considerations seem to have limited propeller diameter and prevented reduction in rpm. Dr. van Manen has apparently counted on the application of improved sterns and nozzles to maintain the efficiency of the heavily loaded propellers of larger and larger ships. Perhaps he will care to comment on this point.

J. D. van Manen

In reply to Prof. Lewis I will mention a total efficiency of about 71 percent in Fig. 2(c) is only based on statistical data.

H. Lackenby (The British Shipbuilding Research Association)

I should like to raise one or two points on Dr. van Manen's paper concerning the speeds and powers of displacement ships.

Firstly, it is stated in his Introduction that up to 1940 the maximum shaft horsepower which could be installed per shaft in a merchant ship was about 10,000. I am sure the author is referring here to single screw ships and I think perhaps that this ought to be stated. For multiple screw ships much higher powers per shaft were, of course, installed.

In this connection it is also stated that 16,000 shp is now normal and that 20,000 is frequently encountered. This is followed by the statement that at the same time tanker speeds have increased from 10 to 17 knots. This is quite true of course, but I think it might be mentioned that this speed increase was largely a natural consequence of increasing size and that in many instances it was a question of keeping the speed-length ratio about the same and increasing the speed according to the square root of the length. In other words there was a significant speed advantage in having a longer ship.

The author's references to the larger block coefficients now being associated with the high deadweight supertanker are of particular interest, and it is interesting to recall how views on this have changed, bearing in mind that between the wars one authority advised that no seagoing ship should have a block coefficient greater than 0.75. According to Fig. 2(b) we find that the largest block coefficient for the Wageningen models plotted there is about 0.825. It might be of interest to mention here that the British Shipbuilding Research Association in conjunction with Ship Division, NPL, are now endeavoring to develop ocean-going forms with block coefficients up to 0.85.

Next, a point about the economic comparison between a conventional and a submarine tanker. It is stated in the paper that for 20,000 tons deadweight and a speed of 20 to 25 knots the submarine tanker would have a distinct advantage. One has to be careful here of the basis of comparison—I think this is intended to be a surface tanker of 20,000 tons and 20 to 25 knots speed. This of course is not conventional as regards speed and would certainly be less economical than a commercial tanker of this deadweight which would have a speed round about 15 to 16 knots. I am speaking here, by the way, of economy on the basis of cost per ton-mile of cargo carried. On the other hand, from the military point of view, there may of course be some advantage in carrying the cargo at the faster speed.

J. D. van Manen

In reply to Mr. Lackenby, the 10,000 hp before 1940 refers to a single screw ship.

D. Savitsky (Davidson Laboratory, Stevens Institute of Technology)

The presentations by Mr. Oakley and Dr. van Manen on the subject of high performance ships of the future were indeed stimulating and exciting. The variety of hydrodynamic forms being considered by the authors is expressive of an open mind toward the consideration of solutions to the problem of high speed transport across the ocean.

Common to each of the vehicle forms considered by the authors is the serious problem of negotiating the rough surface of the ocean at high speed—a problem where severity appears to increase exponentially with speed. Partial solutions to the rough water problem are proposed by the use of submerged hull form, hull forms lifted clear of the water by hydrofoils and by ground effect machines flying just above the waves. In each case the roughness of the sea is still a serious disturbance, although to a lesser extent than for a displacement vessel. Clearly, the solutions proposed by each of the authors consist in a vertical displacement from the water surface.

I would like to carry this suggested solution to its logical conclusion and suggest that, for high speed transport over waves, let's leave the water surface entirely. If our mission is to transport material or people from one port to another at high speed, there is obviously no necessity for exposing the high speed vehicle to the serious disturbances of the sea for the entire length of the voyage. Obviously this suggestion leads to the rediscovery of the water based aircraft—especially designed for short range, low altitude, and relatively low speed operation (for an aircraft)—perhaps 200 to 300 miles/hr. Ordinarily I would not propose such a concept at a meeting on Naval Hydrodynamics. However, since the authors have discussed ground effect machines operating just over the waves at speeds of 100 mils/hr or more, I feel they have strayed sufficiently from the area of conventional hydrodynamic forms to allow me the freedom to do likewise. I feel that as the GEM concept is developed further and further, its appearance will be more like that of an aircraft. If this is to be the case, let us immediately consider the role of the water based aircraft for the short range transport vehicle. A well designed seaplane can easily develop a lift-drag ratio of 20 at altitude. Perhaps this can be increased by flying at low altitude (in moderate ground effect) yet out of the range of the severe wave disturbances of a sea state. To obtain equivalent lift-drag ratios, the GEM would probably need a static thrust augmentation factor of nearly 40, which would necessitate its operation at very low height-diameter ratios. For operation in a sea state of moderate severity, then, the length of the GEM would probably be upwards of 500 or 600 feet in order to achieve the required height diameter ratios and still just clear the waves. Clearly such a large GEM craft would offer many practical design difficulties—and much research will be required to perfect its development.

On the other hand, research in the hydrodynamics of water based aircraft has been supported by the U. S. Navy for over 25 years and the success of this concept has been demonstrated time and again in the form of numerous prototypes which have been successfully designed. If the large GEM is to be considered for oceanic transport, I submit that a very hard and serious reexamination of the water based aircraft be considered for the same mission. Obviously the hovering ability of the GEM is not contained within the capabilities of a specially designed seaplane—but I have not heard the authors contend that this was an important consideration in their studies. Certainly, the GEM will find usefulness as a special purpose vehicle, but as a general working member of the family of everyday transport vehicles, perhaps other concepts will excel.

H. P. Rader (Vosper Limited)

The authors did not mention a type of high speed craft in which we are particularly interested, i.e., the hard chine planing craft. I think this may be of some interest because we have achieved speeds in excess of 50 knots with hard chine planing craft which have been in service for some time. I cannot say offhand how the performance curve of our craft compares with the performance curve of the other craft shown by the authors, because we did not have the papers in time for carrying out such a comparison. May I, therefore, submit the following table for your information and consideration. The figures quoted apply to a hard chine craft weighing about 100 tons.

Speed (knots)	Horsepower/ton
40	71
45	87
50	105
55	126

One more point concerning propellers. In the section on Types of Propellers Dr. van Manen states, "For reasonable application of a supercavitating screw with a diameter of 1 meter, a minimum speed of 54 knots is desirable." In our opinion this minimum speed is much lower, I would say between 40 and 45 knots, depending on the rate of advance or, to be more precise, on the local cavitation number at which the blade sections have to work.

J. D. van Manen

In reply to Mr. Rader, although I failed to mention the hard chine planing aircraft in my paper, I am sure they will be included in subsequent papers.

Owen H. Oakley

I agree with Mr. Savitsky that the water based seaplane operating in ground effect is a logical configuration to consider for the ram wing GEM concept. The very high L/D values which are theoretically obtainable are most intriguing, and I feel confident that this area will receive increased attention as the GEM concept develops.

For ignoring the hard chine planing craft in my discussion I apologize; it would have been of interest to make a comparison of this type with the hydrofoil and the GEM. However, I have made a rough comparison of lift over drag based on Mr. Rader's figures. For this I took the liberty of interpreting horsepower per ton as shp over displacement and applied an assumed propulsive coefficient of 0.5 to get at ehp and drag. This gave L/D values as follows: 7.8, 7.2, 6.6, 6.1. These are about in the low hydrofoil range but probably exceed what hovering GEMs may be expected to attain.

With regard to Mr. Newton's comments concerning control, motions, and performance in a seaway for all these craft, I must agree these matters are critical. I support his plea for more research in this area. The strength of ground effect craft resting on the water is of great importance. Since the weight available for structure in these craft is not great, sophisticated structures similar to those of aircraft will have to be used. Even with the advanced technology of the aircraft industry this problem promises to be formidable.

Mr. Newton quoted an appropriate piece of poetry regarding the ability of the water beetle to stay afloat as long as he did not stop to think about it. I wish to respond in kind with a verse which has a similar theme but which bears on a situation we find ourselves faced with in this delightful country, namely the quantities of delicious food we encounter:

"Eat all kind nature doth bestow
It will amalgamate below;
But if you once begin to doubt
The gastric juice will find it out."

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