Air Cushion Craft Propulsion

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Craft that derive at least partial support from a layer of pressurized air between them and the surface over which they travel offer a wide choice of possible propulsion mechanisms through use of media both above and below the surface interface. The hydrodynamic efficiency of both conventional and novel propulsion mechanisms is considered and presented on a comparative basis of thrust loading. The limits of compressibility and cavitation, where applicable, are included and rapid design charts presented. Efficiency must always be tempered with weight in any given design, and the paper considers the machinery weight of various propulsion units for possible air cushion craft use. Some model and full-scale tests at the General Dynamics facilities are outlined to indicate the potential of the power savings of this form of craft.

Nomenclature

A_j = disk area of propulsor (prior to any vena contracta)
bhp = brake horsepower of propulsion engine
C = peripheral length of craft
C_D = drag coefficient $D/\frac{1}{2}\rho V^2 A_j$
C_{Li} = integrated design lift coefficient of propeller blade
C_T = thrust coefficient $T/\frac{1}{2}\rho V^2 A_j$
D = drag or resistance of craft or propeller diameter
h = daylight clearance of air cushion craft
J = advance ratio of propeller V/nD
K = friction and elevation energy loss coefficient for water jet [Eq. (7)]
k = speed parameter for craft $\frac{1}{2}\rho V^2/(W/S)$
L = lift of craft
n = rotational speed of propeller, revolutions/sec
P = power, hp
p = pressure
p_{st} = static pressure in water at propeller depth
p_v = vapor pressure of water
Q = flow of air required to support craft
S = base supporting area of air cushion craft
shp = shaft horsepower
T = thrust
thp = thrust horsepower required
V = speed of advance of craft
W/S = static supporting pressure of craft
δ = drag parameter of craft at given conditions
η = Froude efficiency of propulsive device
η_p = pump efficiency
ρ = density of medium in which propulsive device does work
ρ_a = air density at ambient conditions

Introduction

THE modern urgent motivation to provide a more versatile and faster marine craft for both naval and transoceanic commerce has prompted a new look into the capabilities of the air cushion craft. These craft, as exemplified by the commercial service of the SRN-5's across San Francisco Bay and their military service in Vietnam, give a new dimension to the nautical world by providing a ship that is relatively independent of the surface over which it travels, and thus give a flexibility of operation unattainable in other forms of transportation.

The uniqueness in this type of craft lies in its at least partial support upon a layer of pressurized air between the craft and the surface over which it travels, be it water or land. The many craft types, plenum, peripheral jet, recirculation, sidewall, etc., that have evolved since the first successful air cushion craft, the Westland SRN-1, flew in 1959, witness the variety of methods tried to harness this unique form of transportation. All craft, however, have a common characteristic in their proximity to the interface and thus have a choice of media for propulsion. This paper considers the area of major interest today, namely, the marine environment, where the choice is between air and water.

The literature is replete with designs to minimize power requirements and the need to devise suitable propulsive means, as emphasized by Cockerell's[1] notation "the propulsion problem" in 1963 (Fig. 1), where he notes that a 3000-ton 100-knot craft would need 75 propellers of 20-ft diameter. The present paper seeks to provide guidelines to designs of the future with regard to propulsion devices and their thrust and weight characteristics.

Classification of Propulsive Devices

There are basically two means available to the air cushion craft designer: jet reaction and momentum exchange as characterized by the jet and the screw.‡ Figure 2 provides a schematic breakdown of how these two physical mechanisms emerge as propulsive hardware in the media of interest to the marine air cushion craft designer.

Invariably, the approach to a propulsion problem is to consider first the efficiency of the system and then its specific machinery weight to meet a particular thrust and speed requirement. A similar approach will be used here for the propulsion of air cushion craft.

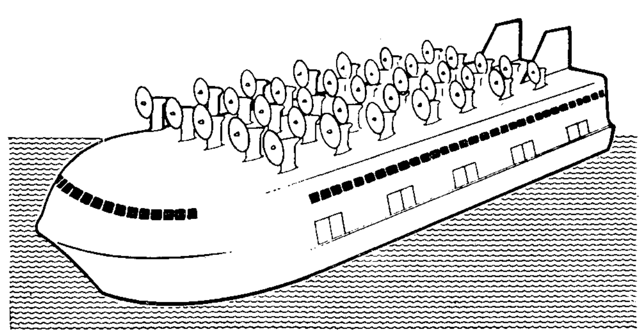

Fig. 1 The propulsion problem.

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‡ For the present paper, propulsion by some form of buoyant rolling friction on the water surface, as tried in some other marine craft, is excluded.

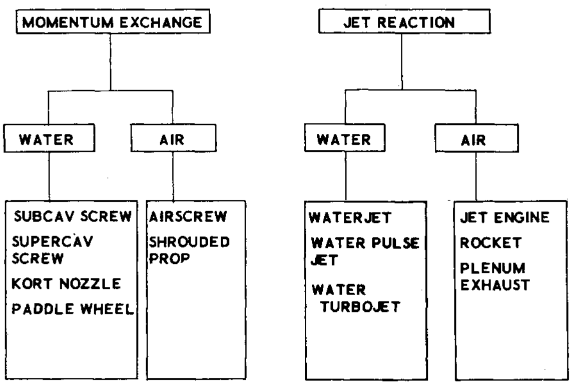

Fig. 2 Available propulsion methods.

Thrust and Propulsive Efficiency

By definition, the over-all efficiency of a propulsive system is given as

$$\eta_p = \frac{\text{useful work out}}{\text{energy supplied}} \tag{1}$$

where the useful work out or work done by the propelling fluid can be equated to the energy supplied by the prime mover only after proper account has been taken of all losses. These losses include energy absorption in the transmission, internal thermodynamic engine losses, and interference effects between the craft and the propulsor.

A variety of methods may be found in the literature which express the efficiency of a total system in various ways. Two examples, of pertinent interest here, are the marine screw and the airscrew approach, which can be used for illustrative purposes.

Consider the marine screw propulsion system, where it is usual to write

$$\eta_p = \eta_H \eta_R \eta = [(1 - t)/(1 - w)] \cdot \eta_R \cdot (TV/\text{shp}) \tag{2}$$

The propulsive efficiency can be recognized as the product of the hull efficiency, the rotational efficiency, and the open water or Froude efficiency of the propeller. The hull efficiency is the result of flow losses incurred by the presence of the hull ahead of the propeller. In this pusher propeller configuration, the flow is disturbed to give rise to a thrust deduction (t) and a wake velocity reduction (w) incurred by the velocity gradient from the viscous flow off the hull. It can be seen that different geometric arrangements of screws and hull (sidewall in the case of some air cushion craft) can give rise to hull efficiencies greater than or less than unity dependent upon the relative magnitudes of t and w. It is normally taken to be about unity, but the reader is referred to the literature (e.g., Ref. 2) for more detailed discussion. The rotative efficiency incurred by nonaxial flow into the propeller is again subject to detailed study but is normally, in good design, of secondary importance when compared to the Froude efficiency of the propeller, which is a function of disk area, blade geometry, and speed of advance. The present paper will be concerned with this open water component of the total efficiency.

In the case of the airscrew, a similar treatment is used except that the "hull efficiency" does not appear per se for the conventional tractor configuration, and the drag of any appendages, nacelles, or shrouds is accounted for in the drag breakdown of the craft. Augmentation of the thrust by any shrouding, and therefore increasing the effective efficiency, is included in the estimate for the Froude efficiency to be considered here.

Note that in both the marine and the airscrew, the preceding brief discussion has accounted for losses only from the propelling fluid side of the propeller to the shaft. A transmission efficiency (normally around 90–95% for simple transmissions) must be applied to convert from the shp to the bhp of the engine.

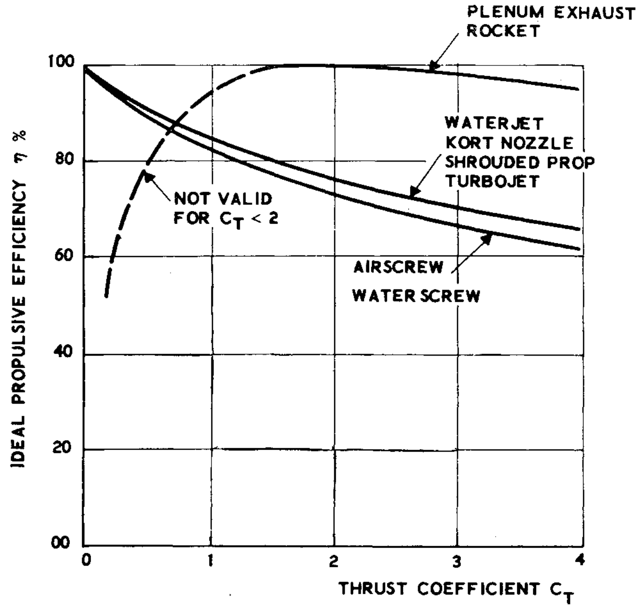

Fig. 3 Maximum comparative efficiencies.

For the present paper, the discussion on propulsive efficiency has been restricted to a discussion of the Froude efficiency (η), both ideal and actual, for the various propulsive devices available to the air cushion craft. By considering each of the basic propulsive mechanisms available and by employing classical momentum theory, together with experimentally determined losses, a comparison can be made of their relative capabilities of producing thrust.

Ideal Propulsive (Froude) Efficiency

The classical Froude theory considers the thrust (T) generated by a "magic disk" of area A_j that ejects rearward a stream of fluid at velocity V_j, thus propelling the craft forward at a velocity V. Since all real fluid effects are neglected, the theory provides a comparative upper bound to the efficiency of the propulsive device for any given disk loading or thrust coefficient C_T defined as

$$C_T = T/\tfrac{1}{2}\rho V^2 A_j \tag{3}$$

The classical results are presented in Table 1. Graphically, these results appear in Fig. 3.

Unfortunately, the ideal theory predicts the same efficiency for various propulsive devices, and it is only the real fluid effects that separate one from the other. The possibility of design parameter choices for each propulsion device, from activity factor, blade section through advance ratio to jet velocity ratio, makes comparison difficult, but as will be

Table 1 Maximum efficiency (ideal)

Curve	Propulsive device	Froude efficiency	Thrust coefficient C_T	Valid region
A)	Unshrouded propeller (water & air)	$\frac{2}{1 + (1 + C_T)^{1/2}}$	$\frac{2V_j}{V}\left(\frac{V_j}{V} - 1\right)$	$Ct > 0$
B)	Shrouded propeller (water & air) Kort nozzle, waterjet, turbojet	$\frac{4}{3 + (1 + 2C_T)^{1/2}}$	$\frac{2V_j}{V}\left(\frac{V_j}{V} - 1\right)$	$Ct > 0$
C)	Airjet, rocket	$\frac{2(2C_T)^{1/2}}{2 + C_T}$	$2\left(\frac{V_j}{V}\right)^2$	$Ct > 2$

seen, the disk loading provides a good comparative measure between the many possible choices. The real fluid effects will now be considered for each main type of interest to the air cushion craft designer in the order shown in Fig. 2.

The Waterscrew

For those craft that operate in a marine environment (which covers practically all existing craft to date), the proximity of the water surface suggests that advantage be taken of this higher-density medium for thrust. In the case of sidewall craft or air cushion catamarans, the existence of hydrodynamic surfaces for buoyant or planing support and for stability and control provides a natural housing for either waterjet or waterscrew. For the case of completely air-supported craft, it still may prove advantageous to use the high-density medium (water) for thrust and only pay the penalty of resistance in the low-density medium (air). Such an approach would extend the speed capabilities of the sidewall craft, presently around 20–30 knots, into the speed range of the completely airborne air cushion vehicle. One such approach, to this end, is the 4000-ton British Hovercraft Corporation's Hoverfreighter design, which is to be a peripheral jet air cushion type propelled by waterscrews with a projected speed of some 50 knots. Other ramifications of this approach, which are beyond the intent of this paper, but must be considered in any engineering design, are the improved control and tracking characteristics of the craft over those of the completely airborne craft at these low speeds.

Attention will now be given to the waterscrew, which has proved to be a reliable propulsive device for several hundred years in its environment of subcavitating flow. The supercavitating propeller, on the other hand, is a relative newcomer to the marine field and is still under development. The blade section is radically different for the two types of flow, and care must be exercised in the choice of propeller in the speed range of interest to the air cushion craft, say from 20 to 150 knots.

Probably the most systematic tests conducted on subcavitating waterscrews were done by Troost in 1935 for a

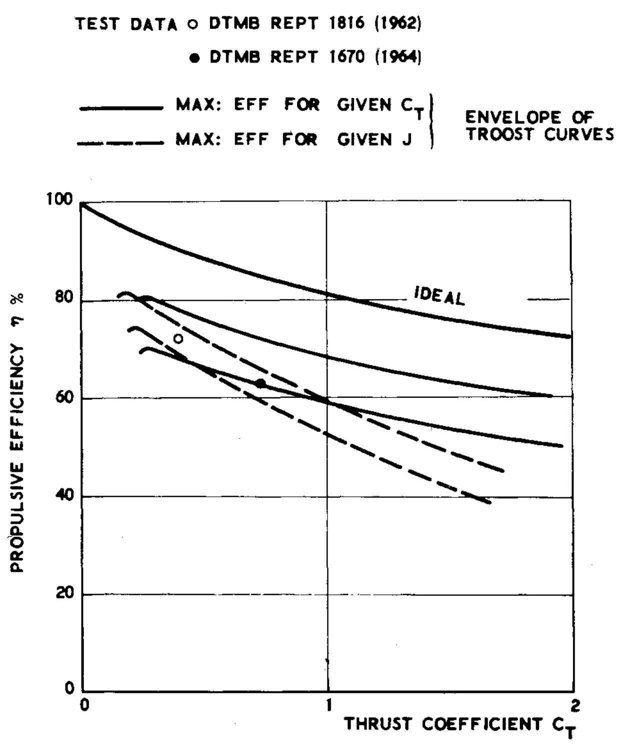

Fig. 4 Efficiency of subcavitating waterscrews.

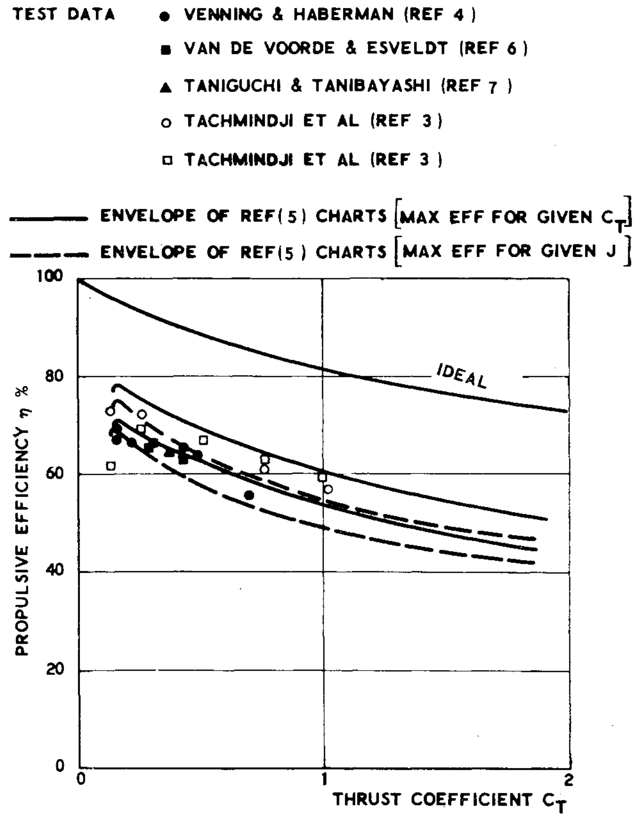

Fig. 5 Efficiency of supercavitating waterscrews.

range of propeller types from 2-bladed through 7-bladed with varying blade area ratios, pitch angles, thrust and power coefficients. The standard charts derived by Troost to cover these test propellers allow for the extraction of maximum efficiencies for several conditions of interest: maximum efficiency for a given disk loading, maximum efficiency for a given advance ratio ($J = V/nD$), and so on. Working from the Troost curves, it will be found that they all fall within the envelope shown in Fig. 4, with the interplay between the number of blades and blade area ratio causing the bandwidth. For low values of disk loading ($0.20 < C_T < 0.60$), the choice between maximum efficiency for a given disk loading or for a given advance ratio is not well defined. Above disk loadings of around 1.0, however, the choice is clear, and it is possible to approximate the 80% of ideal efficiency for the actual efficiency as used in conventional marine practice.§ Some fairly recent test data by Tachmindji[3] on subcavitating screws tend to substantiate the early work by Troost.

The supercavitating waterscrew has developed through the use of airfoil theory, where the cavitated flow is controlled and maintained behind the blade section in its wake. Its advantage is in maintaining high efficiencies at high advance ratios that occur for craft operating above 35–40 knots. As with most high-performance items, requirements for sophistication, including a high degree of structural integrity, pose challenges to the designer. Some recent work with titanium supercavitating propellers appears promising in extending their life in everyday operation.

Venning and Haberman,[4] utilizing the charts of Tachmindji and Morgan,[5] present the corresponding results for the supercavitating waterscrew. Van de Voorde and Esveldt,[6] Taniguchi and Tanibayashi,[7] and Tachmindji and Morgan,[5] among others, have conducted a series of tests on supercavitating waterscrews which would suggest that the actual efficiency approaches some 75% of the ideal efficiency over a wide range of disk loadings, as shown in Fig. 5.

§ See, for example, Ref. 17.

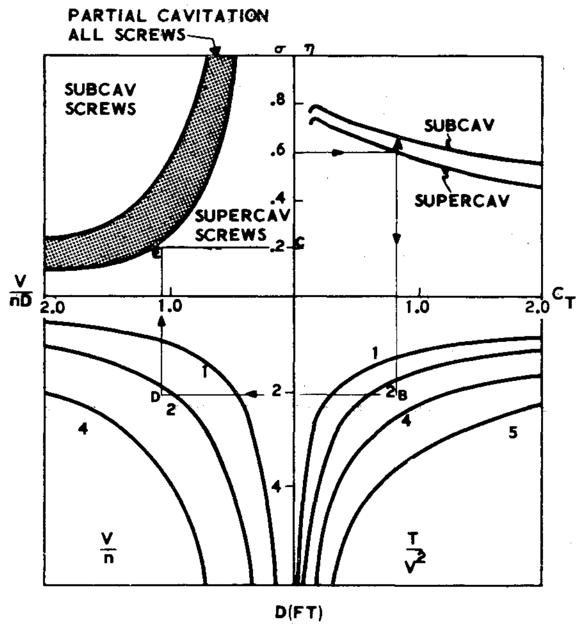

Fig. 6 Predesign chart for waterscrews.

Predesign Charts for Waterscrews

When the air cushion craft designer is attempting to optimize his waterscrew propulsion system to meet the thrust and power requirements, he must contend with cavitation. The cavitation number relates the static pressure on the blade surface to the vapor pressure of the water and the dynamic pressure of the oncoming stream, that is:

$$\sigma = (p_{st} - p_v)/\tfrac{1}{2}\rho V^2 \qquad (4)$$

The designer must now optimize his propeller within the limitations of cavitation governed by Eq. (4) and the efficiency as given by Figs. 4 and 5. A chart found useful by the authors in the selection of waterscrews for the propulsion of air cushion craft allows for such an optimization between efficiency, cavitation, diameter, and rpm for a subcavitating or supercavitating waterscrew, once given the thrust (T) requirements of the craft at a specified speed (V). This chart (Fig. 6) combines the efficiencies determined previously with the cavitation chart given by Venning and Haberman[4] and DuCane.[8]

Given the thrust (T) and speed (V) of the craft under consideration (which is described later), this chart provides a rapid iteration and design method. For clarity, the mean efficiency lines have been used in the upper right-hand quadrant, and clearly the reader could substitute the particular efficiency curve of a known propeller and optimize for that particular propeller if so desired. The chart is best explained through use of an example. Consider a 500-ton sidewall craft with a design cruise speed of 60 knots. A performance analysis would show that at this speed the thrust-speed ratio T/V^2 equals 5. For good control and reliability when underway, two propellers would be desirable, say, mounted on each sidewall, in which case T/V^2 equals 2.5 per propeller. The chart may be used in various ways according to the particular problem at hand, but a typical predesign use could be as follows: select a desired or realistic efficiency, say 60%, and extend a vertical line from the efficiency curve at A to the required $T/V^2 = 2.5$ at B, and read the diameter as 2.0 ft. Then, knowing the cavitation number from Eq. (4), i.e., $\sigma = 0.20$ for 60 knots, a line may be extended horizonatally from C into the region for best operation for a supercavitating waterscrew (as given by Venning and Haberman[4]).

Knowing also the engine speed and gear ratio, the V/n value (say 2, corresponding to 3040 rpm at 60 knots) may be located on the constant diameter line from B at a new point D. A vertical line from D extended upwards into the best operating region will intersect the line from C at point E. The designer can now satisfy himself quickly that the propeller chosen is the best to match the propulsion requirements within the limits of cavitation, diameter, maximum efficiency, and speed.

Before other means of water propulsion are considered, the momentum exchange method of propulsion is now directed at the airscrew. This is a natural choice for those designs that are to take advantage of the amphibious capability of the air cushion craft.

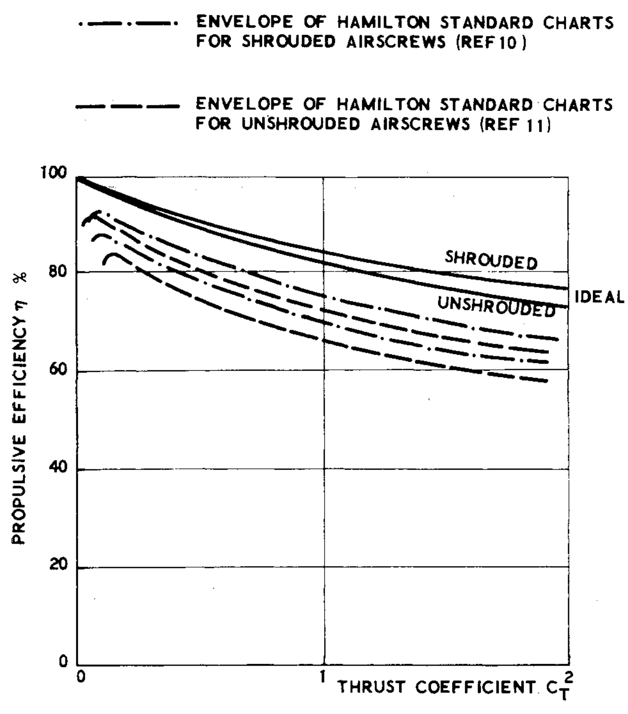

Fig. 7 Efficiency of shrouded and unshrouded airscrews.

The Air Propeller

The low density of air compared to that of water results in much larger diameters for the air propeller, which brings with it the problem of size and space, particularly for the larger craft as noted by Cockerell's sketch (Fig. 1). For craft at least into the 500-ton class, air propulsion is a feasible proposition within the state-of-the-art of air propeller technology.

Various propeller manufacturers have compiled performance charts based on test propellers, ranging from the early work by Fred E. Weick[9] in 1930 to the standard references by Hamilton Standard for shrouded[10] and unshrouded[11] propellers. These charts cover a range of design parameters most likely to be encountered in air cushion craft, including activity factors from 100 to 180, three and four blades, and integrated design lift coefficients from 0.30 to 0.70. The envelope of the maximum efficiencies for all these propellers showed only a $\pm 2\frac{1}{2}\%$ variation in efficiency for a given C_T, as shown in Fig. 7.

It will be noticed from the charts that for a given efficiency, the shrouded air propeller has some 25% gain in thrust capability over that of the unshrouded air propeller as predicted by the simple momentum theory. No comparable data are readily available for the shrouded water propeller as distinct from the long-duct installation. The short-duct arrangement or Kort nozzle has received revived treatment of late (e.g., Ref. 12) and offers advantages in certain applications. The shrouded propeller achieves its thrust augmentation through the increased mass flow by virtue of the maintained disk area downstream of the propeller. Care must be taken, especially for low disk loadings, not to lose this thrust advantage through shroud drag.

The thrust or efficiency advantage is critically affected by the tip clearance between blade tip and duct, and in design (especially for the large-diameter airscrew) structural problems impede the attainment of high efficiency, and the duct weight nullifies the thrust advantage.

In an analogous sense to the waterscrew, the air propeller must contend with maintaining proper flow conditions over its blade section. For the air propeller, the integrated design lift coefficient C_{Li} is related to the local lift coefficient C_l, where

$$C_l = (p - p_0)/\tfrac{1}{2}\rho V^2 \tag{5}$$

must be chosen so as to avoid compressibility losses. A rapid design chart incorporating these features has been constructed (Fig. 8).

By way of comparative example, the same 500-ton craft as used for the waterscrew propulsion example will be given. The reader can follow through the chart in the same manner as before to see that four 25-ft-diam propellers with a design lift coefficient of 0.60 will provide the required thrust at 60 knots. Notice that any attempt to increase the efficiency much beyond 60% would result in a propeller diameter out of proportion with the dimensions of the craft (approximately 200 by 80 ft).

Before considering the various ramifications of the craft types in the thrust-power requirements, consider the two remaining important means of air cushion craft propulsion as depicted in Fig. 2, both of which rely on the principle of jet reaction and possess advantages not inherent in the propeller.

The Waterjet

Propulsion by the ejection of fluid aft has been a familiar means of propulsion to the marine designer since the early 1890's.¶ It has normally been relegated to slow speed barges; however, in fairly recent years a renewed interest has resulted in their use in relatively high-speed planing craft including small pleasure craft commercially available in the 50–350 hp class. The advantages of the waterjet lie not in its efficiency, which is characteristically low at lower speeds, but in its cleanliness of hydrodynamic design. Flush intakes leave a clean hull and no appendages to be fouled by seaweed, rocks, and the like. Propulsion by waterjet has received analytical treatment by many authors[13,14,17,19]

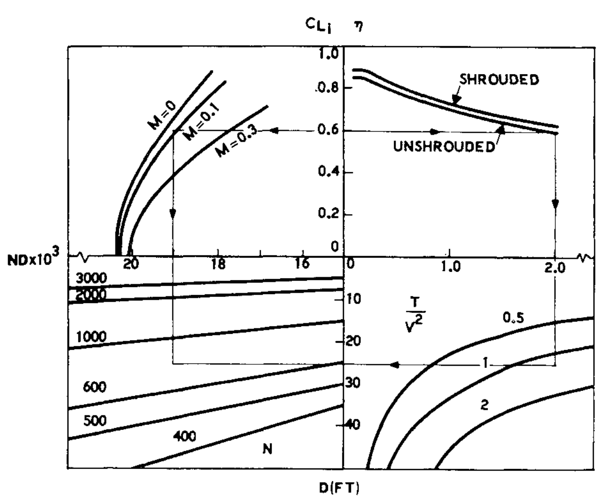

Fig. 8 Predesign chart for air propellers.

¶ See, for example, Ref. 18.

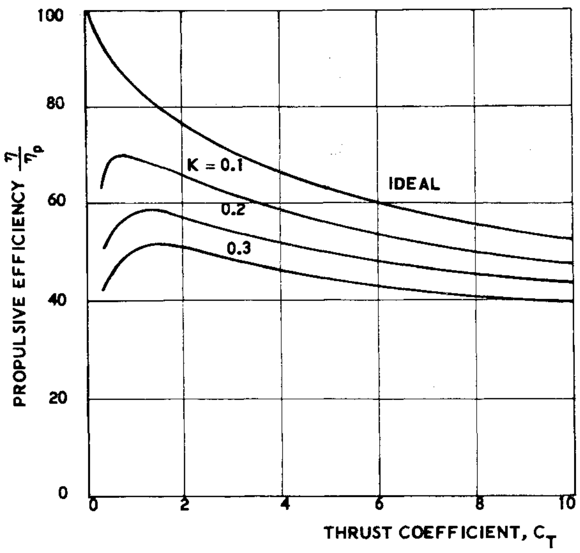

Fig. 9 Efficiency of waterjet.

but experimental evidence is scant. There are two main sources of "lost energy" which may be categorized as friction losses inside the jet pump and an elevation loss incurred through raising the water from the intake to the pumping machinery. In the case of a sidewall air cushion craft, for example, one could envisage the intakes in the sidewall bottoms or sides but with the larger pumping machinery being in the main body of the craft. Design studies are in progress to consider the relative merits of increasing the width of the sidewalls to accommodate lower elevations of pumps and so that they approach catamaran configurations. The trade-off is one of power saved through reduced elevation vs power lost through increased sidewall resistance. Consider first the ideal efficiency for the waterjet, which has been shown in the classical literature to be,

$$\eta = \frac{2}{1 + (V_j/V)} \tag{6}$$

which with typical jet velocity ratios of 3:1 would give an ideal efficiency of 50%. If one bases the friction losses on the exit jet velocity (following Levy[15]) but includes an elevation loss (according to Johnson[14]), again referred to jet velocity, one would arrive at an actual efficiency, referred to the pump efficiency, as given by

$$\eta = \frac{2V_j/V - 1}{(1 + K)(V_j/V)^2 - 1} \tag{7}$$

where K is an energy loss term given by

$$K = K_L + (2gh/V_j^2) \tag{8}$$

and where K_L is the Darcy-Weisbach friction loss term plus any turning, expansion, and contraction losses. In this context, h is the height of the waterjet above the mean water level. Figure 9 indicates the variation of propulsive efficiency with increasing loss factor K, and shows the relatively constant variation from ideal efficiency for the thrust coefficients of 2 and higher.

It remains for experiment to establish a range of geometries and pump elevations before conclusive results can be given for the waterjet propulsion system. It is known that various agencies are working toward this end at the present time. Suggested optimal procedures would be to compare the virtues of high pump pressure and low flow with low pump pressures and high flow in relation to machinery size and efficiency.

Fig. 10 The Britten-Norman CC-5.

Water Turbojet and Pulse Jet

Two other possibilities that are receiving at least exploratory treatment may well evolve compact designs suitable for use on air cushion craft. The water turbojet would utilize a two-fluid working media, with the high-density water mixed with a low-density, high-energy gas to minimize turbine sizes. A modification of such a design utilizing exhaust gas from a turbojet could provide a versatile propulsive device applicable over the wide speed range capability of the air cushion craft.

The pulse jet would use chemical means of combustion, say, the addition of an alkali metal to water, to provide superheated steam to drive the relatively compact turbines. The problems of salt deposit and corrosion would have to be tackled in any such designs of the future.

The Airjet

Apart from technical considerations of a propulsion system for the air cushion craft, there are the considerations of safety and comfort of the personnel or public who come in close proximity to these craft, be it for military or commercial use. For example, with the exception of a few diehards who live at the end of airport runways, the public will only accept the noise of piston or jet aircraft if 1) the airports are far away from where they live, or 2) the aircraft climbs away from the town on takeoff so that the noise is rapidly dissipated by distance. The commercial operators of the hovercraft in England face a singular problem with the propeller-driven craft because 1) the hoverports are closer to the town centers and 2) the hovercraft remain at sea level and so do not dissipate their noise so easily. There are several solutions to this, one of which has already been discussed, that is, hydrodynamic propulsion, and the other is propulsion by airjet. An attractive example of this is the Britten-Norman CC-5 (Fig. 10).

The availability of pressurized air already flowing through the lift system suggests that an integrated lift-propulsion system may well have attractive features for air cushion craft propulsion. The question remains as to the efficiency of such a device and the relative merits of, say, propulsion by airscrew or airjet. The ideal efficiency given in Table 1 suggests good efficiency even at high thrust coefficients, which is desirable in order to reduce disk area. Compare the airscrews and the airjet as depicted in Fig. 11.

One can construct analyses of varying degrees of sophistication. Taking a simple representative case, assume that the thrust required of the propulsive device must overcome the external resistance (D_E) of the craft, plus recover the momentum loss (D_M) through the fan intake (i.e., assume that the air is brought to rest inside the craft before being exhausted to the rear for propulsion). Then

$$T = T_E + D_M \tag{9}$$

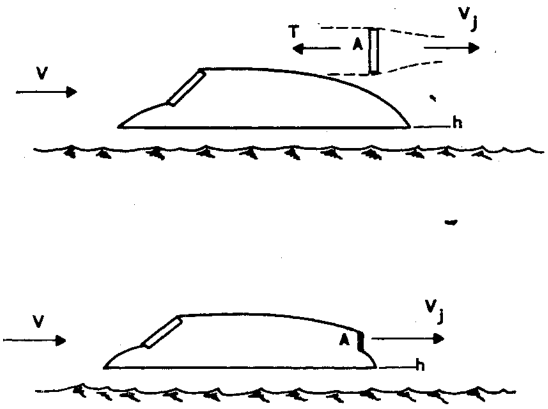

Fig. 11 Airscrew or airjet propulsion.

If the drag coefficient C_D is referred to the supporting area S and the momentum drag is $\rho_a QV$ for the craft, a distance h above the surface, then it is easy to show that for the airscrew,

$$C_T = \frac{S}{A_j}\left[C_D + \frac{2}{(k)^{1/2}}\cdot\frac{Ch}{S}\right] \tag{10}$$

and for the airjet,

$$C_T - (2C_T)^{1/2} = \frac{S}{A_j}\left[C_D + \frac{2}{(k)^{1/2}}\frac{Ch}{S}\right] \tag{11}$$

where k is the ratio of the dynamic pressure of the oncoming airstream to the static supporting pressure of the craft,

$$k = \frac{\frac{1}{2}\rho_a V^2}{W/S}$$

Figure 12 presents these results as a function of the thrust coefficient C_T.

It is seen that there is no mathematical optimum as to the choice of airscrew or airjet, and the engineering choice is based upon the compatiblity of the size of the propulsive device with the size of the craft. For the same craft type, i.e., the same drag coefficient, same relative speed (k), and same relative height (Ch/S) above the surface, the area ratio S/A_j indicates that the airscrew is larger in size compared to the more compact airjet but retains a higher efficiency due to the lower thrust coefficient (which is inversely proportional to the airjet area). In this context, it is seen that small craft on the order of 2–20 tons could make effi-

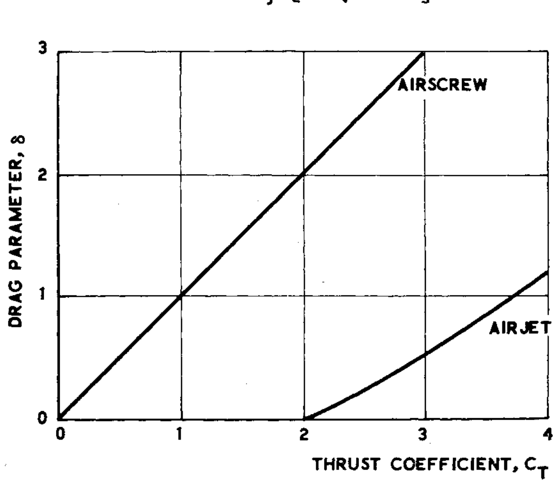

Fig. 12 Propulsion by airscrew or airjet.

cient use of airjet propulsion but that above these sizes too much air flow would be required to maintain sufficient thrust. Future development along these novel lines may well bring into being a new family of quiet air cushion craft without external whirling machinery.

The Turbofan

Both the jet and the propeller have been discussed in the propulsion of air cushion craft, and it is only natural to ask if the turbofan is adaptable to such craft. Such installations have received some exploratory treatment to date, and only a brief remark will be given here. Normally, it is taken that the jet engine is acceptable only at high speeds (300–400 mph) and not acceptable, because of its low efficiency, at speeds of interest to the air cushion craft designer. Lightweight, simple machinery, compactness, and lack of external whirling propellers are also of concern in any design, and the turbofan certainly provides these desirable features. One can envisage at low speeds the hot jet exhaust being used for thrust and the cold fan air diverted to the cushion for lift. At high speeds, the cold fan air can be diverted away from the cushion (with its lower air flow requirements) and used for increased thrust. Reference 16 considers briefly the relative flow and power requirements for air cushion craft as a function of size and concludes that large craft (of the order of 100 tons and larger) can make efficient use of high-bypass-ratio turbofans for integrated lift and propulsion system designs. It is hoped that more investigation will be conducted along these lines to establish guidelines to design.

Propulsion System Weight

It is not sufficient, of course, merely to design any given craft around the efficiency; considerable thought must be given to the weight of machinery to accomplish the task. The air cushion craft has not sufficient history to provide much in the way of statistical data. Fragmentary evidence will be given here to guide future designs and provide comparison with other types of craft.

The prime mover or engine weight is shown best by information collected from the various engine manufacturers (Fig. 13). The relatively recent active development of gas turbine technology, both for aircraft and marine use, has

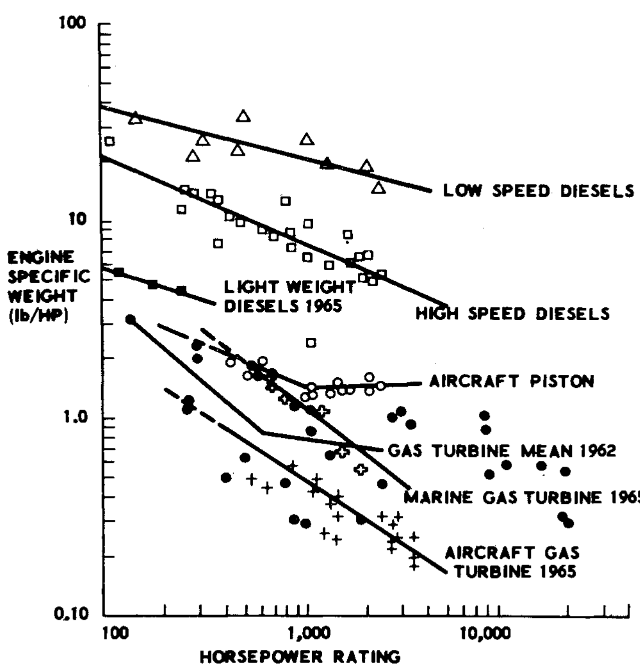

Fig. 13 Engine specific weight.

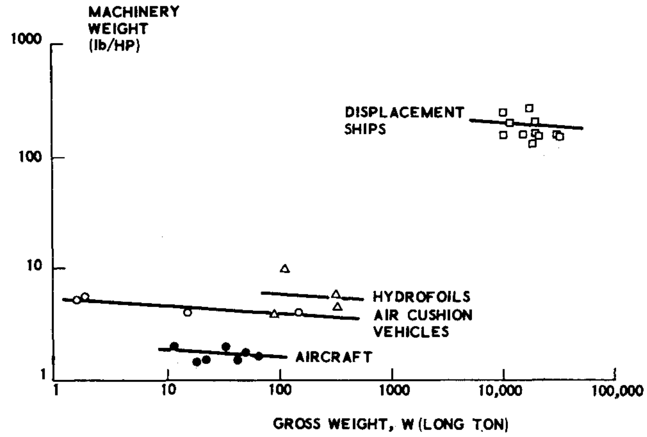

Fig. 14 Machinery specific weight.

caused a wide scatter in the engine specific weight, but it is generally agreed that the marine gas turbine, which is of particular interest to the air cushion craft, will retain a 0.50 lb/hp above 3000 hp.

Unfortunately, the engine weight is only a small portion of the total machinery weight. When the remaining components such as fans, shafts, gearboxes, etc., are added to comprise the machinery, the specific machinery weight approaches almost an order-of-magnitude increase, as shown in Fig. 14. For existing air cushion craft, values approaching 4–5 lb/hp are not uncommon for the total system (lift and propulsion) weight. Designs, however, are evolving where the power requirements are less than earlier designs such that the propulsive machinery can be reduced considerably.

Conclusions

The air cushion craft, as has been shown, can take advantage of a variety of methods of propulsion to accomplish its task or mission. One major aim of this type of craft, of course, is to provide high-speed transportation, particularly in the marine environment, without the penalties of exorbitant power requirements, so often the bane of comparable means of transportation.

It has been shown[16] that the air cushion craft can compete with other existing craft in the speed range of interest and that its full potential has not yet been reached. General Dynamics is actively pursuing a program to explore in detail the power requirements of air cushion craft and the best means to integrate these requirements with the method of propulsion. One substantial tool in this program is the fully instrumented man-carrying research craft SKIP-I (Fig. 15), which will be able to evaluate various propulsion systems in a marine environment.

One intermediate step between an air cushion craft such as SKIP-I and a displacement ship is an air-cushion-supported catamaran hull. An early design under test at the Tow Basin of the Electric Boat Division Marine Technology

Fig. 15 General Dynamics SKIP-1.

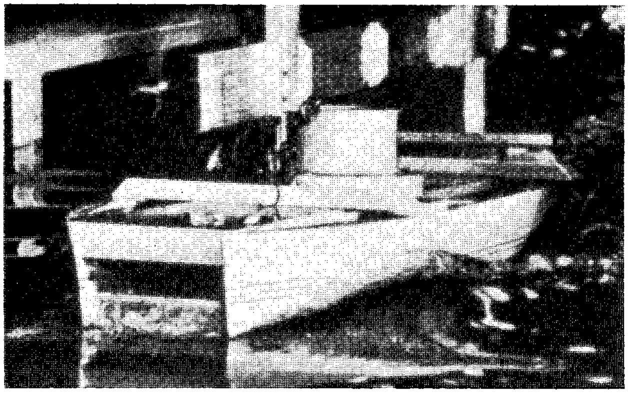

Fig. 16 Air cushion catamaran test model.

Center is shown in Fig. 16. In these tests the air cushion principle is applied to a catamaran hull to reduce its draft and so reduce the propulsive power requirements, yet still retain the good hydrodynamic stability characteristics of the catamaran configuration. A typical result (Fig. 17) shows that with a moderate air cushion power requirement, the hump drag was reduced by more than 20%—a significant improvement in the propulsion of these hull forms.

The present paper has sought to present in a short space some of the propulsion devices available to the air cushion craft and to indicate the developmental area of interest in this relatively new field of transportation.

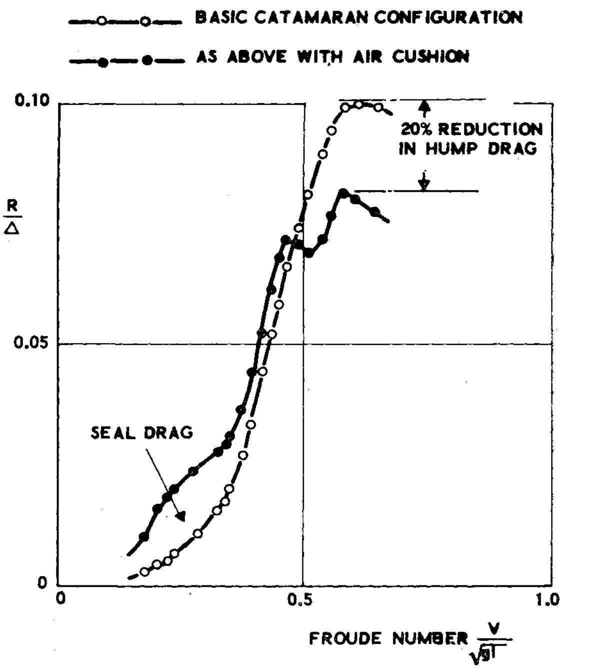

Fig. 17 Model resistance test data.

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