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TECHNICAL MEMORANDUM 85/213
July 1985

A NEW PROPELLER PERFORMANCE PREDICTION METHOD FOR CONCEPT EXPLORATION MODELS FOR DISPLACEMENT SHIPS

Walter E. Ellis

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A NEW PROPELLER PERFORMANCE PREDICTION METHOD FOR CONCEPT EXPLORATION MODELS FOR DISPLACEMENT SHIPS

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Approved by B.F. Peters A/Director/Technology Division

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ABSTRACT

A new propeller performance evaluation method has been developed for use in Concept Exploration Models (CEM) for conventional destroyer-sized ships. The method, based on the use of a Wageningen-B series propeller, is simple and convenient to implement, provides outputs of efficiency and propeller rotational speed, and can be used to simulate fixed-pitch or controllable-pitch propeller installations.

The Wageningen-B propeller is shown to be the most suitable of four candidate propellers for current CEM applications. Used in conjunction with the large diameters now considered feasible, this propeller gives near-optimum efficiency and produces the conditions of propeller loading and rotational speed currently favoured for good acoustic performance.

RESUME

On a mis au point une nouvelle méthode d'évaluation du rendement des hélices applicable à des modèles d'exploration de concept (MEC) pour des navires de la taille des destroyers. La méthode, basée sur l'utilisation d'une hélice de la série Wageningen-B, est simple et facile à mettre en application, donne des valeurs du rendement et de la vitesse de rotation de l'hélice et peut être utilisée pour simuler les installations d'hélices à pas fixe ou à pas réglable.

L'hélice Wageningen-B se révèle la plus adéquate des quatre hélices envisagées pour les applications de MEC actuelles. Utilisée avec les grands diamètres maintenant considérés réalisables, cette hélice donne un rendement presque optimum et des conditions de charge et de vitesse de rotation d'hélice qui ont actuellement la préférence pour un bon rendement acoustique.

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NOTATION

d_{cp}	controllable pitch hub diameter	ft
d_{fp}	fixed pitch hub diameter	ft
D	propeller diameter	ft
D_a	maximum allowable propeller diameter	ft
D_o	optimum diameter (for peak efficiency)	ft
D_t	allowable diameter when D = T	ft
EAR	expanded area ratio	
J	advance ratio	
J_a	advance ratio at $D = D_a$	
J_o	advance ratio at $D = D_o$	
K_T	thrust coefficient	
(K_T/J^2)	thrust loading coefficient	
$(K_T/J^2)_a$	thrust loading coefficient at $D = D_a$	
$(K_T/J^2)_o$	thrust loading coefficient at $D = D_o$	
N	propeller rotational speed	rpm
N_a	propeller rotational speed at $D = D_a$	rpm
N_o	propeller rotational speed at $D = D_o$	rpm
N_p	number of propellers	
N_t	propeller rotational speed at D = T	rpm
P/D	pitch-diameter ratio	
$(P/D)_a$	pitch-diameter ratio at $D = D_a$	
$(P/D)_o$	pitch-diameter ratio at $D = D_o$	
$(P/D)_t$	pitch-diameter ratio at D = T	
R	total resistance	lb
T	draft	ft

v	ship speed	ft/s
V_k	ship speed	kt
η	open water efficiency	
η_a	open water efficiency at $D = D_a$	
η_o	open water efficiency at $D = D_o$	
$\eta_{o_{cp}}$	controllable pitch open water efficiency	
$\eta_{o_{fp}}$	fixed pitch open water efficiency	
η_t	open water efficiency at $D = T$	
ρ	mass density of sea water	$lb - s^2/ft^4$ (Slugs)
σ	cavitation number	

1. INTRODUCTION

This report describes the selection of a new propulsion algorithm for computer-based concept exploration models (CEM's) for conventional warships of the destroyer type. In recent years much of the emphasis of DREA's hydrodynamics research program has shifted from high performance vehicles to more conventional types, characterized by design speeds of 35 knots or less, together with use of efficient, relatively quiet propellers. The Newton-Rader propeller series featured in previous DREA concept exploration models[1] had been selected because of their reasonably good efficiency over a broad speed range, including speeds up to 50 knots. However, they were not particularly appropriate for lower speed applications requiring high efficiency and low noise. It was therefore necessary to define new propeller characteristics which would be appropriate for the new requirements, and to determine a method for predicting propeller rotational speed and pitch angle for use in a machinery selection algorithm.

Reference 2 contains data in a useful format for a number of suitable modern propeller series having higher blade area ratios and/or sub-cavitating sections, and therefore lower noise and higher efficiency, than the previously-used Newton-Rader propellers. The investigation described herein has been carried out to determine the relative merits of three of the most likely substitute series and to recommend a data base and characterization method for a new propulsion algorithm which would meet the contemporary requirements.

2. BACKGROUND

The propeller performance characterization subroutine used in the CEM's SHOP3 and SHOP4[1] was written to evaluate propeller performance at speeds up to 50 knots. A Newton-Rader propeller (with expanded area ratio of 0.49) was used as a source of data because it offered the necessary performance at the highest speeds and was also able to satisfy lower-speed requirements. The convenience of a common algorithm for all ships regardless of size and speed made this a reasonable approach.

The concept exploration phase of ship design is inherently lacking in detailed design information, and so a data format was used in SHOP4 which avoided any reference to propeller rotational speed, presented performance data for an optimum diameter as a function of ship speed, and applied a correction factor when the diameter was limited by hull geometrical constraints to less than the optimum. Optimum diameter is defined as the diameter which gives the maximum possible efficiency at a given speed. Allowable propeller diameter was assumed to be a simple function of hull draft.

The above technique has the following drawbacks when considering a contemporary CEM which emphasises lower speeds and the avoidance of cavitation.

1. The Newton-Rader propeller is not appropriate for quiet operation.
2. A considerable amount of work would be required to convert data for a more suitable propeller into the same format.
3. Information on rotational speed is desired for use in a machinery selection sub-routine.
4. The method depends on the assumption of controllable-pitch propellers, since the optimum efficiency is obtained over a range of pitch angles. This restricts the scope of propulsion system evaluations by excluding all fixed-pitch installations.
5. There is a general lack of confidence in the validity of Newton-Rader data among the technical community, whereas the other propellers under consideration are in common use and their performance characteristics are not in doubt.

Thus there was a requirement to develop a new characterization method which would overcome these limitations. This study describes how the new algorithm was devised.

3. STUDY PLAN

The approach was to evaluate and compare the performance of the original and three other propeller types in powering a variety of ships of the destroyer/frigate type. The analysis was based on a number of hypothetical ships for which resistance and draft data at several speeds were available. The ship specifications were originally devised as part of a comprehensive survey of future ship options and therefore thoroughly covered a very broad range of speeds and displacements. Several hull forms were also represented, so that a range of drafts and resistances was involved at each speed. The characteristics of the twenty-four ships used in the analysis are summarized in Table 1. Propeller performance calculations were performed at the indicated speeds. Most ships had twin screws, but the largest required three screws to achieve 40 knots.

Propeller performance calculations were made for each ship, using data from Reference 2 in the method described in the following sections. Some simplifying assumptions were made. The cavitation numbers were calculated by the CEM method of assuming a propeller hub draft of ten feet for all ships, whence

$$\sigma = (31.22/V_k)^2 \tag{1}$$

The resulting cavitation numbers coincide reasonably well with those for which data are available (Table 2), so that no interpolation was attempted, the data being taken at the cavitation numbers indicated. This procedure gives adequate performance estimates for comparison of propeller types, considering the other simplifying assumptions involved.

In common with the CEM approach, no allowances were made for wake or thrust deduction, all comparisons being made on open water efficiency.

Also in common with the CEM approach, published fixed pitch propeller data were assumed to be valid for controllable pitch propellers of the same blade area ratio. This procedure is for convenience in making comparisons, and a later section will present a correction factor for controllable-pitch installations.

Four propellers were investigated, beginning with the three-bladed Newton-Rader type with an expanded area ratio (EAR) of 0.49 featured in SHOP4. Three potential replacements were selected from those described in Reference 2. The principal basis of selection was that they should have an expanded area ratio as large as possible, the limit being set by the need for the blades to pass each other when going to reverse thrust (controllable pitch propellers being assumed). The limit is usually assumed to be about 0.70 - 0.72 but this had to be relaxed a little to accommodate the values represented in the propeller series. A three-bladed Newton-Rader with an EAR of 0.73 was chosen to illustrate the effect of simply increasing blade area while retaining the same blade section, a three-bladed Gawn-Burrill with an EAR of 0.665 represented conventional flat-faced design, and a five-bladed Wageningen-B with an EAR of 0.75 represented more modern, but still conventional, design.

4. PERFORMANCE EVALUATION

The results of the evaluation of all four propellers are contained in Table 3, which was constructed according to the procedures described in the following sections.

4.1 Newton-Rader (EAR = 0.49)

This propeller was used in the SHOP4 propulsion algorithm, which first determines the propeller diameter required to realize the maximum possible efficiency at a given speed, compares it with the actual (maximum allowable) diameter and makes the appropriate correction to the efficiency, as shown in Figure 1. The result is a value of open-water efficiency. In this study, it was desired to obtain a more detailed view of the intermediate steps in the process, and so a manual calculation was adopted, using the data given in Reference 2.

The analysis proceeded as follows. For a particular design speed and cavitation number, the appropriate propeller performance chart of Reference 2 was examined. Figure 2 shows a typical chart for this propeller. The maximum open-water efficiency η_o, (point A in Figure 2) was located, if necessary by interpolation to an intermediate pitch-diameter ratio, and corresponding values for optimum pitch-diameter ratio $(P/D)_o$, advance ratio J_o, and thrust loading coefficient $(K_T/J^2)_o$ were identified. The values are the same for all ships at a given design speed. The values of $(P/D)_o$ and η_o were entered in Table 3.

A detailed analysis was then performed for each ship. The optimum propeller diameter, previously defined as the diameter which produces the maximum open-water efficiency, was calculated from the definition of thrust loading coefficient (neglecting thrust deduction)

$$K_T/J^2 = R/(\rho v^2 N_p D^2) \qquad (2)$$

whence

$$D_o = [R/\rho v^2 N_p (K_T/J^2)_o)]^{1/2} \qquad (3)$$

The corresponding rotational speed N_o was calculated from the definition of advance ratio

$$J = \frac{101.3\ V_k}{ND} \qquad (4)$$

whence

$$N_o = \frac{101.3\ V_k}{J_o D_o} \qquad (5)$$

Values of D_o and N_o were recorded in Table 3 for each ship at this design speed. The entire procedure was repeated for each design and cruise speed.

The next step was to calculate the maximum allowable diameter for each ship. This is the largest diameter which can be installed within the geometrical constraints. Following SHOP4 practice, this was assumed to be

$$D_a = 0.875T \qquad (6)$$

A notable feature of this Newton-Rader analysis is that for twin-screw ships at all speeds and for triple-screw ships at design speed, the allowable diameter was always less than the optimum, and the peak efficiency could therefore not be achieved. In the case of the triple-screw ships at cruise speed, the optimum diameter was lower than the maximum allowable diameter. However, the maximum allowable diameter had still to be assumed since this diameter had to be used to meet the design speed. Thus, in every case the actual performance corresponding to the use of the allowable diameter (chosen to satisfy design speed requirements) had to be determined.

This was accomplished by calculating a new thrust loading coefficient based on the allowable diameter from

$$(K_T/J^2)_a = R/(\rho v^2 D_a{}^2 N_p) \qquad (7)$$

and re-entering the appropriate propeller curves at this $(K_T/J^2)_a$ to obtain the highest possible efficiency (η_a) (if necessary by interpolation of P/D curves) and corresponding $(P/D)_a$ and J_a. The rotational speed N_a corresponding to the allowable diameter was calculated from

$$N_a = \frac{101.3\ V_k}{J_a D_a} \tag{8}$$

The values of D_a, η_a, $(P/D)_a$ and N_a were recorded in Table 3.

A parallel analysis was performed using the SHOP4 method with manual calculation of optimum diameter and diameter ratio (D_a/D_o) and values of optimum and actual efficiency read from Figure 1. In all cases the results agreed within one and one-half percent and usually within one-half of one percent with the results from the detailed analysis described above.

4.2 Other Propellers

A simplified analysis of the three other propellers was adopted, prompted by the observation that the optimum diameter could not be obtained for the first propeller (Newton Rader P/D=0.49). This analysis began with the calculation of performance based on the maximum allowable diameter, using equations (6) and (7) to determine the point of entry to the performance charts for the evaluation of η_a, $(P/D)_a$, and J_a. N_a was calculated using equation (8). The appropriate values were recorded in Table 3.

Data were not available at the lower cavitation numbers corresponding to 40 and 45 knots for the Gawn-Burrill and Wageningen-B propellers, but these speeds are beyond the current range of interest.

The point of entry $(K_T/J^2)_a$ was compared with the point of peak efficiency $(K_T/J^2)_o$ in each case. With the exception of three triple-screw ships at cruise speed fitted with Wageningen-B propellers, $(K_T/J^2)_a$ was always higher than $(K_T/J^2)_o$, indicating that D_a was less than D_o. Since the optimum efficiency could not be attained, a full analysis of optimum performance was not undertaken. However, η_o and $(P/D)_o$ were identified and D_o was evaluated for each ship by using equation (3). Results are shown in Table 3. N_o was not calculated.

5. DISCUSSION OF DATA

The results presented in Table 3 represent a first look at propeller characteristics and are derived solely from a quest for the maximum efficiency at a given diameter. In a practical case, many trade-offs in efficiency, pitch and rpm would be considered with an eventual compromise being reached which might negate some of the critical comments to be made below. Some such trade-offs will be discussed later. Nevertheless, the present approach is feasible in the context of a CEM, where a simple selection strategy must be adopted.

Table 3 presents the data ship by ship so that the effect of speed on propeller preformance can be readily seen. Note that the same basic trends can be observed fairly consistently over the whole set of subject ships, encompassing a variety of hull forms and consequently a broad range of resistances and drafts.

The comments on performance which follow refer to the allowable or achieveable results rather than the optimum.

5.1 Newton-Rader (EAR = 0.49)

It is obvious from the results for the Newton-Rader (EAR = 0.49) propeller listed in Table 3 that there is a marked discrepancy between the optimum and allowable propeller diameters which decreases, but does not disappear, with decreasing speed. This has a significant impact on performance at high speed, both in reducing efficiency and in increasing propeller rotational speed. The latter may be somewhat high from acoustical considerations, but might be beneficial in terms of transmission weight. Efficiency is good at cruise speeds; and here, design trade-offs would incur small penalties.

The data show a minor dependence on pitch variation to achieve the desired performance. In a few cases, more extreme variations are necessary but these apply to large, fast, triple-screw ships of little current interest.

5.2 Newton-Rader (EAR = 0.73)

Compared to the previous propeller, this type offers better efficiency at high speeds (over 35 knots), about equal performance at the design speeds of most interest (30-35 knots), and significantly lower efficiency at cruise speeds. The discrepancy between optimum and allowable diameter at the speeds of most interest (15-35 knots) is even greater than the previous propeller and more extreme pitch variations are frequently required to achieve satisfactory results.

There seems to be no good reason to favour this propeller over the other Newton-Rader type.

5.3 Gawn-Burrill (EAR = 0.665)

This propeller is not suitable for 40 knot operation, but this is above the design range of current interest. Its efficiency closely parallels that of the Newton-Rader (EAR=0.49), with a slight superiority at 30 knots. N_a is somewhat lower. Again some pitch variation is necessary.

This propeller might be considered as a replacement by virtue of its established reputation were it not for the superior characteristics of the next propeller.

5.4 Wageningen-B (EAR = 0.75)

This propeller is suitable for speeds of 35 knots and below. Its efficiency is significantly better than the Newton-Rader (EAR = 0.49) at design speeds (30 to 35 knots), but marginally lower at cruise speeds. Rotational speeds are lower and perhaps more practical, from a cavitation avoidance viewpoint. An intangible but important advantage is the widespread faith in its data base compared to the Newton-Rader series.

Compared to the Gawn-Burrill propeller, this one has equal efficiency at cruise speeds, but is clearly superior at speeds above 30 knots. A very important consideration is the fact that P/D remains constant over the entire range of cases studied. The importance of this factor will be discussed in Section 7. It should also be noted that the differences between optimum and allowable diameter and efficiency are, in general, the least of all the propellers. Finally, its cavitation avoidance characteristics should be superior to the Newton-Rader (EAR = 0.49) because of its higher expanded area ratio.

5.5 Propeller Selection

On the basis of the foregoing observations, the Wageningen-B propeller is considered to give the best overall performance, and it is recommended for future propeller characterization models.

6. NEW PROPELLER CHARACTERIZATION METHOD

The validity of the foregoing discussion is recognized to be limited by the inequities in some of the parameters, particularly the expanded area ratio. The choice of the Wageningen-B propeller might therefore be questioned, were it not for a further consideration apart from the actual performance values quoted. This has to do with its compatibility with a new characterization method now to be discussed.

An important observation in Table 3 is that only in exceptional cases does the actual diameter come close to the ideal or optimum diameter. This permits the abandonment of the SHOP4 approach in favour of a more straightforward characterization based directly on the allowable diameter, determined from ship geometry. The risk of using too large a propeller, with the consequent loss of efficiency (points to the left of the efficiency peak in Figure 2), is remote for conventional designs. This is discussed more fully in Section 8.

In the new method the thrust loading coefficient (K_T/J^2) approach is retained. Relevant data for the Wageningen-B propeller in the appropriate form are shown in Figure 3, and can be incorporated in a sub-routine with an interpolation procedure for intermediate cavitation numbers. The curves would be entered at the $(K_T/J^2)_a$ determined from equation (7), using a suitably chosen D_a (see below, equation (10)), η_a and J_a would be obtained at the appropriate cavitation number, and N_a calculated using equation (8). The method thereby satisfies the wish to have propeller speed defined.

The particular suitability of the Wageningen-B propeller for this application lies in the facts that its peak performance curves exhibit a well-behaved transition from non-cavitating to partially-cavitating conditions and that the peak performance (over a wide range of K_T/J^2) is obtained at a P/D of 1.4 (as exhibited in Table 3). This results in an orderly family of curves, shown in Figure 3, which can be taken directly out of Reference 1 without further re-computation.

7. FIXED AND CONTROLLABLE PITCH PROPELLERS

A further advantage of using the Wageningen-B propeller data is that, because they all apply to a single pitch-diameter ratio, they permit the incorporation of a fixed-pitch propeller option in a new CEM. This broadens the range of machinery available for installation with the various weight and range trade-offs that are entailed.

The preceding comparisons were made on the assumption that the fixed pitch data of Reference 2 could be assumed to apply to controllable pitch propellers as well. While this is a valid assumption for determining relative merit, the larger hub diameter required for a controllable pitch installation compared to fixed pitch incurs an efficiency penalty which must be included in any new characterization method. The correction factor associated with a controllable-pitch propeller is given in Reference 4 as a function of hub diameters as:

$$\frac{\eta_{o_{cp}}}{\eta_{o_{fp}}} = \frac{1-(d_{fp}/D)^2}{1-(d_{cp}/D)^2} \qquad (9)$$

Typical diameter ratios are: fixed pitch, 0.24; and controllable pitch, 0.32. These values yield a correction factor of 0.95, and the new characterization method will include this factor when controllable pitch installations are being considered. For CE purposes, the rotational speed can be assumed to be unaffected by hub diameter.

8. ALLOWABLE DIAMETER LIMIT

A recent analysis of modern destroyer-frigate hull forms[3] to examine the maximum propeller diameter that could be accommodated within the practical constraints imposed by physical and hydrodynamic considerations determined that, for CE purposes, the equation

$$D_a = T \qquad (10)$$

gave reasonable results. This equation has been adopted for new destroyer CEM's. Compared to the old CEM (Equation 6), it yields larger diameters which can therefore be expected to improve the cavitation characteristics and efficiency of the propeller. The effect of the use of equation (10) with the new characterization method has been examined and the results are given in Table 4.

Here the new allowable diameter has been designated as D_t to avoid confusion with earlier discussion. D_t is calculated from equation (10) and used in equation (7) to determine the point of entry into the curves of Figure 3. Efficiency (η_t) and shaft speed (N_t) are determined as in previous discussions. The ratio of allowable to optimum diameter (D_t/D_o) is also given and η_a and N_a from Table 3 have also been included for comparison.

The results are highly favourable. The new allowable diameter is very close to the optimum in almost every case, and so the new efficiencies are almost always better than those with the smaller diameter D_a. Even when D_t exceeds the optimum value, the difference is not great enough to cause a significant drop off in efficiency, except in the special case of the triple-screw ships at 20 knots. These ships show a modest drop in efficiency, but the results are still very good. Shaft speeds are reduced with consequent acoustical advantages.

9. CONCLUSIONS

A new propeller and characterization method suited to contemporary requirements has been chosen, with significant advantages over the previous method. The Wageningen-B propeller has been selected because it offers generally better efficiency, is more acceptable acoustically, lends itself to the new characterization method, and has a well-founded data base.

The characterization method is simple, straightforward and easy to implement. It produces values of shaft speed and propeller pitch as well as efficiency. A major attraction of the method is that it can be used to simulate fixed and controllable-pitch propellers, by using the data as given for fixed-pitch installations, and by applying a correction factor.

The new characterization method is fully compatible with the use of propellers of larger diameter than previously assumed, giving near optimum efficiency and acoustically attractive shaft speeds.

TABLE 1

CHARACTERISTICS OF SHIPS USED IN THE ANALYSIS

Ship	Hull Form	Displacements, tons	Speed, knots	
			Design	Cruise
A	Planing	500	40,45	15
B		750		
C		1000		
D	Slender	500	40,45	15
E		750		
F		1000		
G	Slender	1500	35,40	15
H		2000		
J		2500		
K	Conventional	1500	30,35	15
L		2000		
M		2500		
N	Slender	3000	35,40	20
P		4000		
Q		5000		
R	Conventional	3000	30,35	20
S		4000		
T		5000		
U	Conventional, twin screw	6000	35	20
V		8000		
W		10,000		
X	Conventional triple screw	6000	40	20
Y		8000		
Z		10,000		

TABLE 2

CAVITATION NUMBERS USED IN THE ANALYSIS

Speed, V_k	Corresponding Cavitation Number	Cavitation Number At Which Data Was Taken From Reference 2		
(knots)	(From Eqn.1)	Newton-Rader	Gawn-Burrill	Wageningen-B
15	4.33	Atmos.	Atmos.	3.5
20	2.44	2.5	2.0	2.0
30	1.08	1.0	1.0	1.0
35	0.80	0.75	0.75	0.75
40	0.61	0.60		
45	0.48	0.50		

TABLE 3. PROPELLER CHARACTERISTICS GROUPED BY SHIP

SHIP	NOMINAL		R	NEWTON-RADER EAR = 0.49				NEWTON-RADER EAR = 0.73				GAWN-BURRILL EAR = 0.665				WAGENINGEN-B EAR = 0.75			
	T	V_k		D_o / D_a	η_o / η_a	P/D^o / P/D^a	N_o / N_a	D_o / D_a	η_o / η_a	P/D^o / P/D^a	N_o / N_a	D_o / D_a	η_o / η_a	P/D^o / P/D^a	N_o / N_a	D_o / D_a	η_o / η_a	P/D^o / P/D^a	N_o / N_a
A	7.56	45	120200	9.84 6.61	0.745 0.67	2.06 1.20	260 757	8.53 6.61	0.738 0.720	2.00 1.58	542								
		40	101300	9.49 6.61	0.76 0.69	2.06 1.22	242 645	9.41 6.61	0.743 0.726	2.06 1.54	489								
		15	17600	8.32 6.61	0.78 0.76	1.25 1.05	162 247	11.09 6.61	0.755 0.730	2.06 1.34	206	9.92 6.61	0.768 0.75	2.0 1.47	208	8.56 6.61	0.765 .755	1.4 1.4	206
B	8.65	45	160000	11.37 7.57	0.745 0.665	2.06 1.20	224 680	9.84 7.57	0.738 0.715	2.00 1.51	489								
		40	136700	11.06 7.57	0.76 0.685	2.06 1.20	207 585	10.93 7.57	0.743 0.723	2.06 1.45	442								
		15	21900	9.33 7.57	0.78 0.76	1.25 1.05	144 215	12.37 7.57	0.755 0.730	2.06 1.34	179	11.07 7.57	0.768 0.75	2.0 1.47	180	9.55 7.57	0.765 .755	1.4 1.4	179
C	9.52	45	197500	12.70 8.33	0.745 0.665	2.06 1.20	200 615	10.93 8.33	0.738 0.715	2.00 1.51	443								
		40	170500	12.37 8.33	0.76 0.675	2.06 1.15	184 553	12.20 8.33	0.743 0.723	2.06 1.45	400								
		15	25800	10.16 8.33	0.78 0.76	1.25 1.05	131 194	13.43 8.33	0.755 0.730	2.06 1.34	162	12.01 8.33	0.768 0.75	2.0 1.47	163	10.36 8.33	0.765 .755	1.4 1.4	162
D	7.06	45	96700	8.86 6.18	0.745 0.680	2.06 1.20	286 776	7.65 6.18	0.738 0.725	2.00 1.63	548								
		40	75800	8.25 6.18	0.76 0.715	2.06 1.32	276 625	8.14 6.18	0.743 0.728	2.06 1.62	487								
		15	12600	7.10 6.18	0.78 0.770	1.25 1.13	188 248	9.38 6.18	0.755 0.736	2.06 1.50	195	8.39 6.18	0.768 0.76	2.0 1.52	212	7.24 6.18	0.765 .760	1.4 1.4	212
E	8.09	45	120600	9.93 7.08	0.745 0.690	2.06 1.30	254 630	8.54 7.08	0.738 0.725	2.00 1.66	470								
		40	101000	9.54 7.08	0.76 0.715	2.06 1.32	238 544	9.39 7.08	0.743 0.728	2.06 1.62	424								
		15	16500	8.16 7.08	0.78 0.770	1.25 1.13	163 216	10.74 7.08	0.755 0.736	2.06 1.50	170	9.60 7.08	0.768 0.76	2.0 1.52	185	8.29 7.08	0.765 .760	1.4 1.4	185
F	8.90	45	147900	10.98 7.79	0.745 0.685	2.06 1.30	229 588	9.46 7.79	0.738 0.725	2.00 1.66	426								
		40	123700	10.56 7.79	0.76 0.710	2.06 1.30	214 503	10.40 7.79	0.743 0.728	2.06 1.62	385								
		15	20100	9.01 7.79	0.78 0.770	1.25 1.13	147 196	11.85 7.79	0.755 0.736	2.06 1.50	154	10.60 7.79	0.768 0.76	2.0 1.52	168	9.15 7.79	0.765 .760	1.4 1.4	168

TABLE 3. (CONTINUED)

SHIP	NOMINAL		R	NEWTON-RADER EAR = 0.49				NEWTON-RADER EAR = 0.73				GAWN-BURRILL EAR = 0.665				WAGENINGEN-B EAR = 0.75			
	T	V_k		D_o / D_a	η_o / η_a	P/D^o / P/D^a	N_o / N_a	D_o / D_a	η_o / η_a	P/D^o / P/D^a	N_o / N_a	D_o / D_a	η_o / η_a	P/D^o / P/D^a	N_o / N_a	D_o / D_a	η_o / η_a	P/D^o / P/D^a	N_o / N_a
G	10.20	40	164300	12.18 8.92	0.76 0.710	2.06 1.25	185 452	11.98 8.92	0.743 0.726	2.06 1.58	343								
		35	131500	11.73 8.92	0.77 0.730	1.66 1.34	202 363	12.55 8.92	0.749 0.730	2.06 1.58	302	12.55 8.92	0.752 0.74	2.0 1.45	341	9.98 8.92	0.760 0.750	1.4 1.4	344
		15	26400	10.36 8.92	0.78 0.770	1.25 1.13	128 171	13.58 8.92	0.755 0.736	2.06 1.50	135	12.15 8.92	0.768 0.76	2.0 1.52	146	10.48 8.92	0.765 0.760	1.4 1.4	146
H	11.22	40	200100	13.48 9.82	0.76 0.700	2.06 1.25	167 414	13.24 9.82	0.743 0.726	2.06 1.58	311								
		35	160300	12.97 9.82	0.77 0.730	1.66 1.34	183 329	13.86 9.82	0.749 0.730	2.06 1.58	274	13.86 9.82	0.752 0.74	2.0 1.45	310	11.02 9.82	0.760 0.750	1.4 1.4	312
		15	32200	11.44 9.82	0.78 0.770	1.25 1.13	116 155	15.00 9.82	0.755 0.736	2.06 1.50	122	13.42 9.82	0.768 0.76	2.0 1.52	133	11.58 9.82	0.765 0.760	1.4 1.4	133
J	12.08	40	234000	14.56 10.57	0.76 0.700	2.06 1.25	155 384	14.30 10.57	0.743 0.726	2.06 1.58	289								
		35	187100	14.02 10.57	0.77 0.730	1.66 1.34	169 306	14.97 10.57	0.749 0.730	2.06 1.58	255	14.97 10.57	0.752 0.74	2.0 1.45	287	11.90 10.57	0.760 0.750	1.4 1.4	290
		15	37500	12.36 10.57	0.78 0.770	1.25 1.13	107 144	16.19 10.57	0.755 0.736	2.06 1.50	113	14.48 10.57	0.768 0.76	2.0 1.52	123	12.50 10.57	0.765 0.760	1.4 1.4	123
K	9.72	35	167100	13.22 8.50	0.77 0.668	1.66 1.15	180 483	14.15 8.50	0.749 0.720	2.06 1.27	396	14.15 8.50	0.752 0.67	2.0 1.40	420	11.25 8.50	0.760 0.715	1.4 1.4	392
		30	130300	12.90 8.50	0.78 0.704	1.66 1.13	160 400	14.34 8.50	0.754 0.718	2.00 1.23	353	13.04 8.50	0.772 0.74	2.0 1.40	333	11.77 8.50	0.768 0.740	1.4 1.4	333
		15	21400	9.31 8.50	0.78 0.780	1.25 1.19	143 167	12.23 8.50	0.755 0.740	2.06 1.66	129	10.94 8.50	0.768 0.76	2.0 1.60	143	9.44 8.50	0.765 0.765	1.4 1.4	150
L	10.69	35	205000	14.63 9.35	0.77 0.668	1.66 1.15	162 438	15.65 9.35	0.749 0.720	2.06 1.27	359	15.65 9.35	0.752 0.67	2.0 1.40	381	12.44 9.35	0.760 0.715	1.4 1.4	356
		30	165000	14.53 9.35	0.78 0.696	1.66 1.10	142 371	16.14 9.35	0.754 0.714	2.00 1.22	327	14.67 9.35	0.772 0.73	2.0 1.40	305	13.25 9.35	0.768 0.730	1.4 1.4	305
		15	25300	10.12 9.35	0.78 0.780	1.25 1.19	131 151	13.30 9.35	0.755 0.740	2.06 1.66	117	11.89 9.35	0.768 0.76	2.0 1.60	130	10.26 9.35	0.765 0.765	1.4 1.4	136
M	11.51	35	240000	15.87 10.07	0.77 0.668	1.66 1.15	150 406	16.97 10.07	0.749 0.718	2.06 1.25	337	16.97 10.07	0.752 0.67	2.0 1.40	353	13.49 10.07	0.760 0.715	1.4 1.4	330
		30	182700	15.30 10.07	0.78 0.704	1.66 1.13	135 337	16.98 10.07	0.754 0.718	2.00 1.23	297	15.44 10.07	0.772 0.74	2.0 1.40	280	13.94 10.07	0.768 0.740	1.4 1.4	280
		15	28700	10.80 10.07	0.78 0.780	1.25 1.19	123 140	14.16 10.07	0.755 0.740	2.06 1.66	109	12.67 10.07	0.768 0.76	2.0 1.60	120	10.93 10.07	0.765 0.765	1.4 1.4	126

TABLE 3. (CONTINUED)

SHIP	NOMINAL		R	NEWTON-RADER EAR = 0.49				NEWTON-RADER EAR = 0.73				GAWN-BURRILL EAR = 0.665				WAGENINGEN-B EAR = 0.75			
	T	V_k		D_o D_a	η_o η_a	P/D^o P/D^a	N_o N_a	D_o D_a	η_o η_a	P/D^o P/D^a	N_o N_a	D_o D_a	η_o η_a	P/D^o P/D^a	N_o N_a	D_o D_a	η_o η_a	P/D^o P/D^a	N_o N_a
N	12.85	40	265000	15.50 11.24	0.76 0.700	2.06 1.25	146 361	15.22 11.24	0.743 0.726	2.06 1.58	272								
		35	212000	14.93 11.24	0.77 0.730	1.66 1.34	159 287	15.94 11.24	0.749 0.730	2.06 1.58	240	15.94 11.24	0.752 0.740	2.0 1.45	270	12.67 11.24	0.760 0.750	1.4 1.4	273
		20	69100	12.99 11.24	0.78 0.775	1.34 1.20	128 174	16.33 11.24	0.752 0.736	2.06 1.55	137	15.30 11.24	0.771 0.760	2.0 1.60	140	12.79 11.24	0.770 0.765	1.4 1.4	152
P	14.14	40	324000	17.13 12.37	0.76 0.700	2.06 1.25	132 328	16.82 12.37	0.743 0.726	2.06 1.58	247								
		35	258000	16.45 12.37	0.77 0.730	1.66 1.34	144 261	17.57 12.37	0.749 0.730	2.06 1.58	218	17.57 12.37	0.752 0.740	2.0 1.45	245	13.97 12.37	0.760 0.750	1.4 1.4	248
		20	84300	14.35 12.37	0.78 0.775	1.34 1.20	116 158	18.04 12.37	0.752 0.736	2.06 1.55	124	16.90 12.37	0.771 0.760	2.0 1.60	127	14.13 12.37	0.770 0.765	1.4 1.4	138
Q	15.22	40	378000	18.52 13.32	0.76 0.700	2.06 1.25	122 305	18.17 13.32	0.743 0.726	2.06 1.58	229								
		35	299000	17.73 13.32	0.77 0.730	1.66 1.34	133 242	18.93 13.32	0.749 0.730	2.06 1.58	202	18.93 13.32	0.752 0.740	2.0 1.45	228	15.05 13.32	0.760 0.750	1.4 1.4	230
		20	98200	15.49 13.32	0.78 0.775	1.34 1.20	107 146	19.47 13.32	0.752 0.736	2.06 1.55	115	18.24 13.32	0.771 0.760	2.0 1.60	118	15.25 13.32	0.770 0.765	1.4 1.4	128
R	12.23	35	271000	16.85 10.70	0.77 0.668	1.66 1.15	141 382	18.01 10.70	0.749 0.718	2.06 1.25	316	18.01 10.70	0.752 0.670	2.0 1.40	332	14.32 10.70	0.760 0.715	1.4 1.4	311
		30	194400	15.79 10.70	0.78 0.713	1.66 1.17	130 303	17.52 10.70	0.754 0.720	2.00 1.24	266	15.93 10.70	0.772 0.745	2.0 1.40	261	14.38 10.70	0.768 0.745	1.4 1.4	259
		20	62900	12.38 10.70	0.78 0.775	1.34 1.20	134 183	15.58 10.70	0.752 0.736	2.06 1.55	144	14.60 10.70	0.771 0.760	2.0 1.60	147	12.20 10.70	0.770 0.765	1.4 1.4	160
S	13.46	35	335000	18.75 11.78	0.77 0.665	1.66 1.10	126 364	10.03 11.78	0.749 0.718	2.06 1.25	287	20.03 11.78	0.752 0.630	2.0 1.40	308	15.92 11.78	0.760 0.695	1.4 1.4	296
		30	219000	16.78 11.78	0.78 0.722	1.66 1.20	123 264	18.60 11.78	0.754 0.723	2.00 1.29	235	16.91 11.78	0.772 0.750	2.0 1.40	235	15.27 11.78	0.768 0.750	1.4 1.4	233
		20	73900	13.42 11.78	0.78 0.775	1.34 1.20	124 166	16.89 11.78	0.752 0.736	2.06 1.55	131	15.82 11.78	0.771 0.760	2.0 1.60	134	13.23 11.78	0.770 0.765	1.4 1.4	145
T	14.50	35	405000	20.63 12.69	0.77 0.650	1.66 1.10	115 350	22.03 12.69	0.749 0.714	2.06 1.22	280	22.03 12.69	0.752 0.630	2.0 1.40	286	17.51 12.69	0.760 0.695	1.4 1.4	274
		30	241000	17.59 12.69	0.78 0.730	1.66 1.25	117 229	19.49 12.69	0.754 0.726	2.00 1.35	209	17.72 12.69	0.772 0.750	2.0 1.40	216	16.00 12.69	0.768 0.755	1.4 1.4	212
		20	83800	14.30 12.69	0.78 0.775	1.34 1.20	116 151	17.99 12.69	0.752 0.736	2.06 1.55	121	16.85 12.69	0.771 0.765	2.0 1.60	123	14.08 12.69	0.770 0.768	1.4 1.4	133

TABLE 3. (CONTINUED)

SHIP	NOMINAL		R	NEWTON-RADER EAR = 0.49				NEWTON-RADER EAR = 0.73				GAWN-BURRILL EAR = 0.665				WAGENINGEN-B EAR = 0.75			
	T	V_k		D_o / D_a	η_o / η_a	P/D^o / P/D^a	N_o / N_a	D_o / D_a	η_o / η_a	P/D^o / P/D^a	N_o / N_a	D_o / D_a	η_o / η_a	P/D^o / P/D^a	N_o / N_a	D_o / D_a	η_o / η_a	P/D^o / P/D^a	N_o / N_a
U	15.41	35	441000	21.53 13.48	0.77 0.655	1.66 1.10	110 317	23.00 13.48	0.749 0.718	2.06 1.25	251	23.00 13.48	0.752 0.630	2.0 1.4	269	18.28 13.48	0.76 0.695	1.4 1.4	258
		20	92800	15.05 13.48	0.78 0.777	1.34 1.18	110 141	18.93 13.48	0.752 0.736	2.06 1.55	114	17.73 13.48	0.771 0.765	2.0 1.6	116	14.82 13.48	0.77 0.768	1.4 1.4	125
V	16.96	35	489000	22.68 14.84	0.77 0.668	1.66 1.15	104 275	24.21 14.84	0.749 0.723	2.06 1.33	216	24.21 14.84	0.752 0.680	2.0 1.4	230	19.25 14.84	0.76 0.725	1.4 1.4	219
		20	109100	16.32 14.84	0.78 0.777	1.34 1.22	102 128	20.52 14.84	0.752 0.738	2.06 1.62	99	19.22 14.84	0.771 0.765	2.0 1.6	105	16.07 14.84	0.77 0.768	1.4 1.4	114
W	18.28	35	538000	23.78 15.99	0.77 0.684	1.66 1.20	100 239	25.38 15.99	0.749 0.723	2.06 1.33	200	15.99	0.680	1.4	213	15.99	0.725	1.4	204
		20	124000	17.41 15.99	0.78 0.780	1.34 1.23	95 114	21.88 15.99	0.752 0.738	2.06 1.62	92	25.38 15.99	0.752 0.765	2.0 1.6	98	20.18 15.99	0.78 0.768	1.4 1.4	106
X	15.41	40	554000	18.29 13.48	0.76 0.710	2.06 1.30	123 289	17.96 13.48	0.743 0.728	2.06 1.62	221								
		20	92800	12.29 13.48	0.78 0.780	1.34 1.38	135 108	15.46 13.48	0.752 0.750	2.06 1.92	90	14.48 13.48	0.771 0.770	2.0 1.8	98	12.10 13.48	0.77 0.760	1.4 1.4	118
Y	16.96	40	672000	20.16 14.84	0.76 0.710	2.06 1.30	112 263	19.79 14.84	0.743 0.728	2.06 1.62	201								
		20	109100	13.32 14.84	0.78 0.780	1.34 1.66	125 92	16.76 14.84	0.752 0.750	2.06 1.92	81	15.70 14.84	0.771 0.770	2.0 1.8	89	13.12 14.84	0.77 0.760	1.4 1.4	108
Z	18.28	40	811000	22.15 15.99	0.76 0.700	2.06 1.25	102 254	21.74 15.99	0.743 0.726	2.06 1.58	191								
		20	124000	14.21 15.99	0.78 0.780	1.34 1.66	117 85	17.87 15.99	0.752 0.750	2.06 1.92	76	16.73 15.99	0.771 0.770	2.0 1.8	83	13.99 15.99	0.77 0.760	1.4 1.4	108

TABLE 4. WAGENINGEN-B CHARACTERISTICS

WITH INCREASED DIAMETER

Ship	V_k	D_t	$\frac{D_t}{D_o}$	η_o	η_a	η_t	N_a	N_t
W	35	18.28	.91	.760	.725	.755	204	166
V		16.96	.88		.725	.750	219	180
U		15.41	.84		.695	.745	258	204
T		14.50	.83		.695	.740	274	218
S		13.46	.85		.695	.745	296	233
Q	35	15.22	1.01	.760	.75	.760	230	191
R		12.23	.85		.715	.750	311	252
P		14.14	1.01		.75	.760	248	205
M		11.51	.85		.715	.750	330	268
N		12.85	1.01		.75	.760	273	226
L	35	10.69	.86	.760	.715	.750	356	288
J		12.08	1.02		.75	.760	290	240
K		9.72	.86		.715	.750	392	317
H		11.22	1.02		.75	.760	312	259
G		10.20	1.02		.75	.760	344	285
T	30	14.50	.91	.768	.755	.765	212	175
S		13.46	.88		.75	.765	233	195
R		12.23	.85		.745	.765	259	214
M		11.51	.83		.74	.760	280	232
L		10.69	.81		.73	.760	305	249
K		9.72	.83		.74	.760	333	274
Z	20	18.28	1.31*	0.770	.76	.735	108	83
W		18.28	1.07		.768	.765	106	87
Y		16.96	1.29*		.76	.740	108	90
V		16.96	1.06		.768	.765	114	95
Q		15.22	1.00		.765	.770	128	108
X	20	15.41	1.27*	.770	.76	.740	118	100
U		15.41	1.04		.768	.770	125	105
P		14.14	1.00		.765	.770	138	116
T		14.50	1.03		.768	.770	133	113
S		13.46	1.02		.765	.770	145	121
N	20	12.85	1.00	.770	.765	.770	152	127
R		12.23	1.00		.765	.770	160	134

TABLE 4 CONT'D

Ship	V_k	D_t	$\frac{D_t}{D_o}$	η_o	η_a	η_t	N_a	N_t
J	15	12.08	.97	.765	.76	.765	123	103
H		11.22	.97		.76	.765	133	111
M		11.51	1.05		.765	.760	126	106
G		10.20	.97		.76	.765	146	122
C		9.52	.92		.755	.765	162	129
L	15	10.69	1.04	.765	.765	.760	136	114
B		8.65	.91		.755	.765	179	148
K		9.72	1.03		.765	.760	150	126
F		8.90	.97		.76	.765	168	140
A		7.56	.88		.755	.765	206	170
E	15	8.09	.98	.765	.76	.765	185	154
D		7.06	.98		.76	.765	212	176

* Triple screws

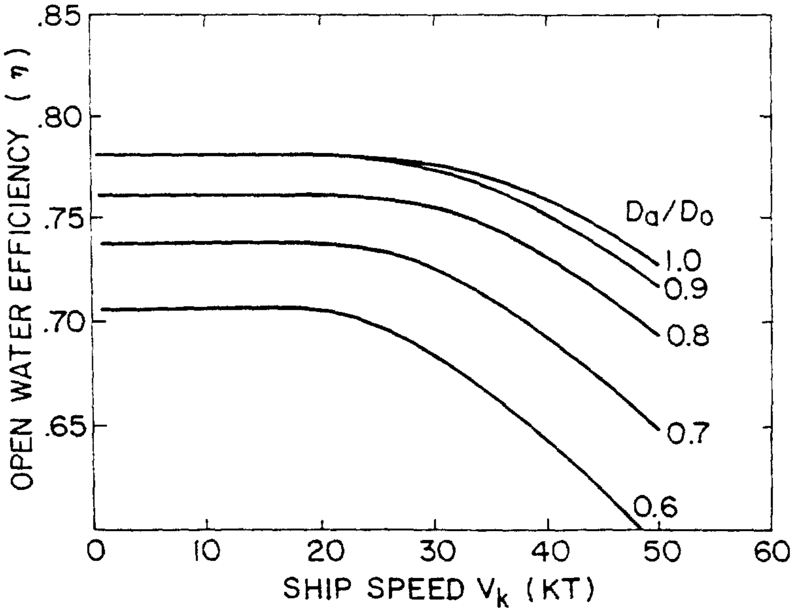

FIGURE 1 - Concept Exploration Method for Determining Open-Water Efficiency

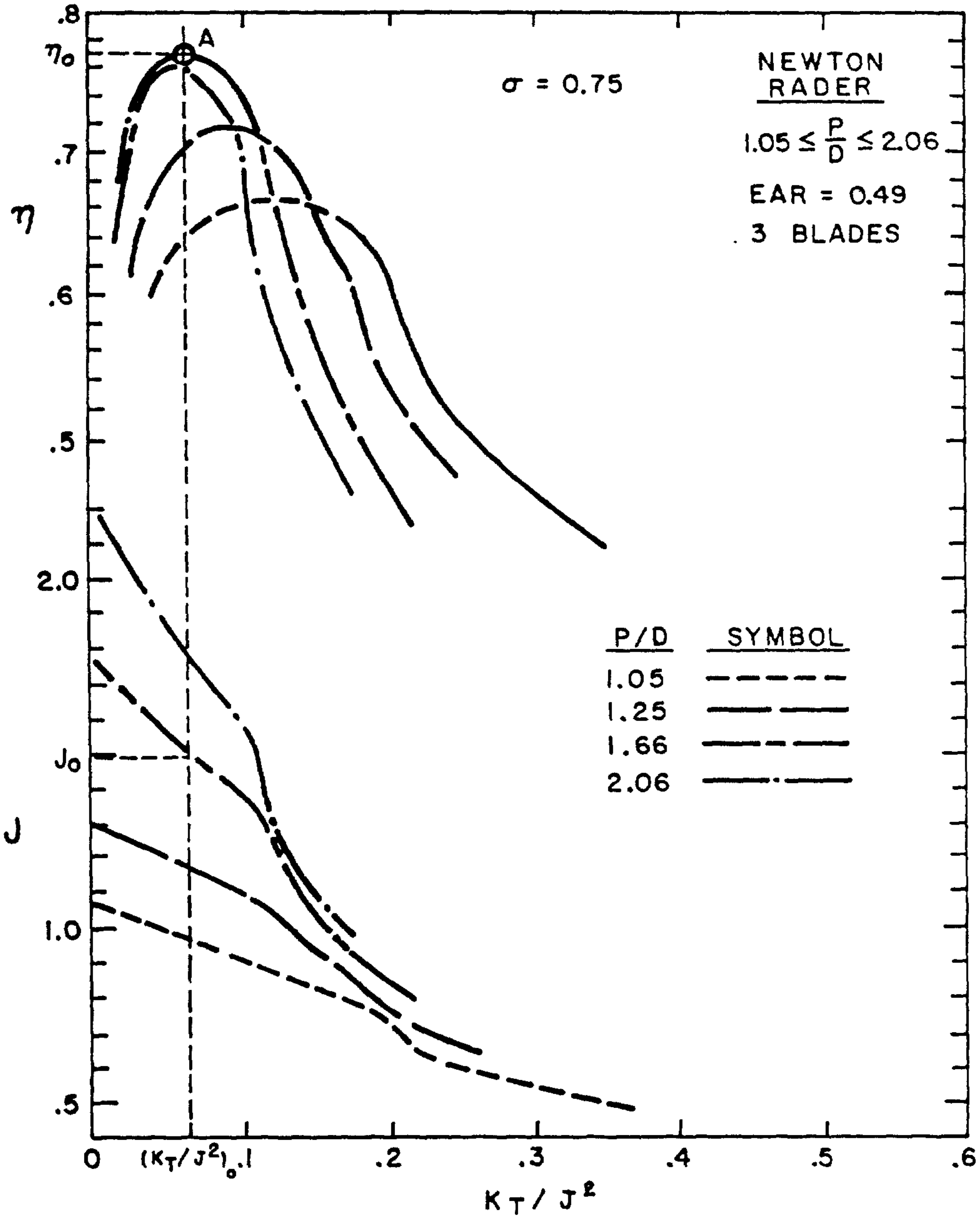

FIGURE 2 - Typical Data Presentation for Newton-Rader Propeller

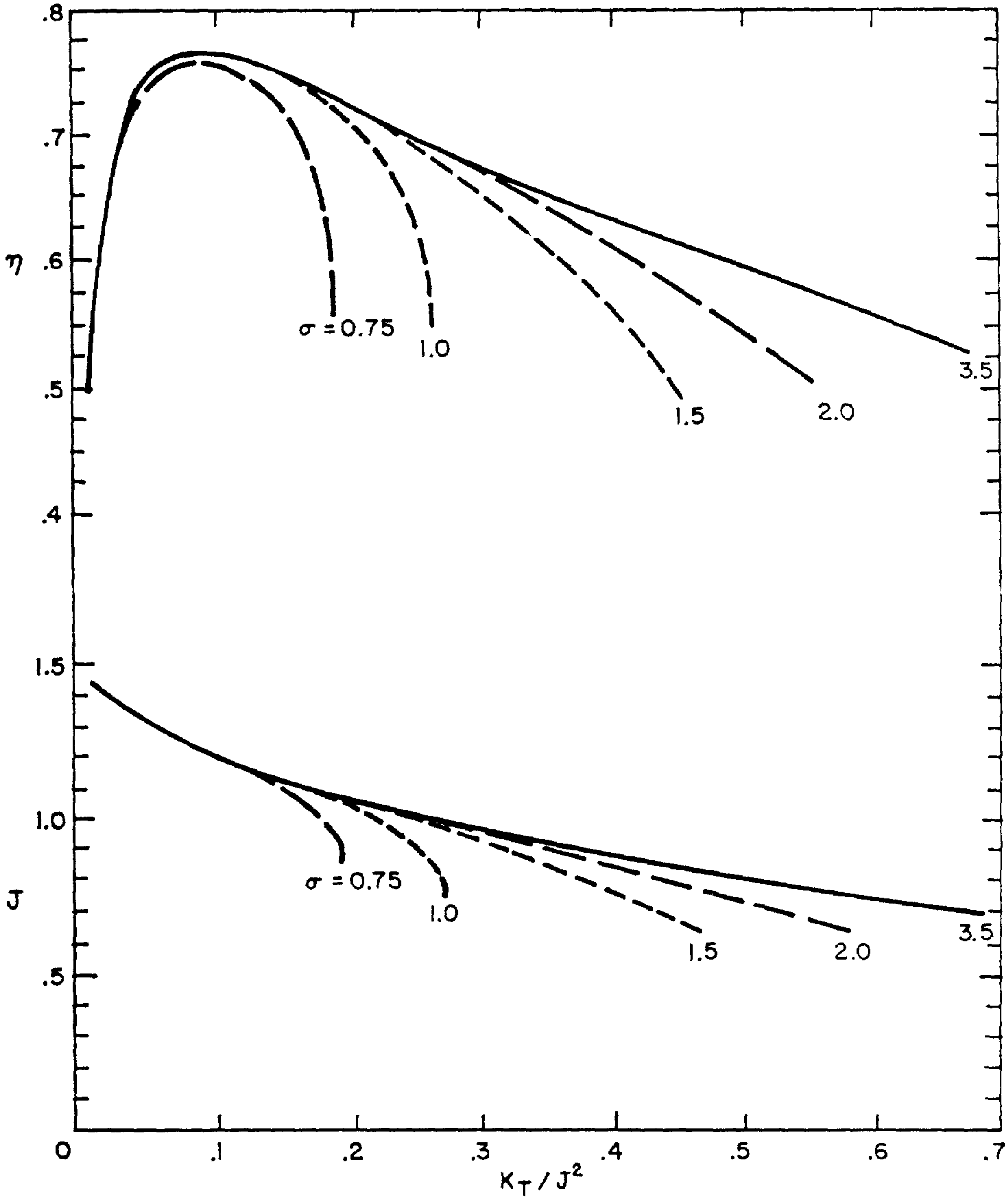

FIGURE 3 – Propeller Performance Chart for Wageningen-B
EAR = 0.75 P/D = 1.4

REFERENCES

1. Eames, M.C. and Drummond, T.G.: "Concept Exploration - An Approach to Small Warship Design", Royal Institution of Naval Architects Transactions, Volume 119, 1977.

2. Blount, Donald L. and Fox, David L.: "Design Considerations for Propellers in a Cavitating Environment", Hampton Roads Section, Society of Naval Architects and Marine Engineers, 29 September 1976.

3. Ellis, Walter E.: "Subroutines for Determining the Geometry and Resistance of Small Warship Appendages", DREA Technical Memorandum in review.

4. Wind, J.: "Hub Size Selection Criteria for Controllable Pitch Propellers as a Means to Ensure Systems Integrity", Naval Engineers Journal, December 1978.

UNCLASSIFIED

Security Classification

DOCUMENT CONTROL DATA – R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall document is classified)

1 ORIGINATING ACTIVITY	2a. DOCUMENT SECURITY CLASSIFICATION 2b GROUP
3 DOCUMENT TITLE A New Propeller Performance Prediction Method for Concept Exploration Models for Displacement Ships	
4 DESCRIPTIVE NOTES (Type of report and inclusive dates)	
5 AUTHOR(S) (Last name, first name, middle initial) Ellis, Walter E.	

6. DOCUMENT DATE JULY 1985	7a. TOTAL NO OF PAGES 28	7b. NO. OF REFS 4

8a. PROJECT OR GRANT NO.	9a ORIGINATOR'S DOCUMENT NUMBER(S) DREA TECHNICAL MEMORANDUM 85/213
8b. CONTRACT NO.	9b. OTHER DOCUMENT NO.(S) (Any other numbers that may be assigned this document)
10 DISTRIBUTION STATEMENT	
11 SUPPLEMENTARY NOTES	12. SPONSORING ACTIVITY

13. ABSTRACT

A new propeller performance evaluation method has been developed for use in Concept Exploration Models (CEM) for conventional destroyer-sized ships. The method, based on the use of a Wageningen-B series propeller, is simple and convenient to implement, provides outputs of efficiency and propeller rotational speed, and can be used to simulate fixed-pitch or controllable-pitch propeller installations.

The Wageningen-B propeller is shown to be the most suitable of four candidate propellers for current CEM applications. Used in conjunction with the large diameters now considered feasible, this propeller gives near-optimum efficiency and produces the conditions of propeller loading and rotational speed currently favoured for good acoustic performance.

DSIS
70-070

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Security Classification

KEY WORDS

Marine propellers
Concept Exploration Models
Ship design
Simulation

85-03251
#48020

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