NRC Publications Archive
Archives des publications du CNRC

Design and optimization of an ice class propeller under shallow water, semi-tunnel hull and heavy load conditions

Liu, P.; Islam, M.; Searle, S.; Neill, A.; Prior, A.

Publisher's version / Version de l'éditeur:

OMAE2006-92027

DESIGN AND OPTIMIZATION OF AN ICE CLASS PROPELLER UNDER SHALLOW WATER, SEMI-TUNNEL HULL AND HEAVY LOAD CONDITIONS

Pengfei Liu*
Institute for Ocean Technology, National Research Council, St. John's, NL Canada A1B 3T5
Email: Penfei.Liu@nrc.ca

Mohammed Fakhrul Islam
Faculty of Engineering and Applied Sciences, Memorial University of Newfoundland, St. John's, NL Canada A1B 3X5

Shawn Searle
Oceanic Consulting Corporation Ltd, St. John's, NL Canada, A1B 2X5

Andrew McNeil
Oceanic Consulting Corporation Ltd, St. John's, NL Canada A1B 2X5

Andrew Prior
Fleetway Inc., Suite 800, 141 Laurier Avenue West, Ottawa, Ontario, Canada K1P 5J3

ABSTRACT

A design and optimization procedure developed and used for a propeller installed on a twin-semi-tunnel-hull ship navigating in very shallow and icy water under heavy load conditions is presented. The base propeller was first determined using classical design routines under open water condition utilizing existing model test data. In the optimization process, a panel method code (PROPELLA) was used to vary the pitch values and distributions and take into account the inflow wake distribution, tunnel gap and cavitation effects. The optimized propeller was able to numerically achieve a ship speed 0.02 knots higher than the desired speed and 0.06 knots higher than the classical B-series propeller. The analysis of the effect of inflow wake, hull tunnel, cavitation and blade rake angle on propulsive performance will be the focus of this paper

INTRODUCTION

With the development of computational technology, numerical expertise and increasing demand of propellers working under extreme conditions, conventional design method alone has long been inadequate for designing these propellers. Computational hydrodynamic methods have a great advantage of reducing the cost of manufacturing model propellers and facility time, and providing some performance results that could be very difficult to obtain in model tests. There exist huge amount of publications on lifting surface and panel method codes to evaluate hydrodynamic performance of a marine propeller. For example, Kerwin and Lee [Kerwin and Lee 1978], presented a hydrodynamic evaluation code by using a lifting surface method. The first application of panel method which was a more advanced method, for marine propellers was presented by Hess and Valarezo [Hess and Valarezo 1985]. Few of these lifting surface theories or panel methods codes were applied and presented for a detailed design and optimization process, or in other words, very few marine propeller design cases that fully utilized numerical codes were documented in literature. A couple of these examples includes a scientific fishing ship propeller design by using the panel method code [Hotaling et. al. 2001] and a podded propeller that was designed by using an in-house panel method code [Bertaglia et al. 2004]. This work is to develop and use such a procedure to design and optimize a propeller and to shed some lights as a guideline on marine propeller design and optimization.

PROCEDURE AND METHOD

This section describes the design and optimization procedure and method. They were divided in to the following subsections:

- *__Given conditions__* that were obtained from a self propulsion report [Baranowski 2005], including ship data with constraints, resistance and power prediction data for minimum required propulsion efficiency, sea trial propulsion data for minimum thrust requirement and maximum allowable torque requirement;
- *__Base propeller geometry determination__* in terms of pitch and expanded area ratio that employs a classical B_P-δ design method with a Wageningen B4 type propeller of several expanded area ratios in terms of minimum required area based on cavitation;
- *__New base propeller determination__* that contains the method of determining the new base propeller, which is mainly a combination of the classical method with analysis in consideration of particular working conditions; and
- *__Optimization of the new base propeller__* that includes a brief introduction of the panel method code and optimization in terms of the variation of pitch values and distribution under the full scale cavitation number, with the hull effect and inflow wake that is surveyed and extrapolated for full scale. During optimization, the in-house panel method code *PROPELLA*, along with pre- and postprocessors were used.

PROCEDURE AND METHOD

This section describes the design and optimization procedure and method. It is divided in to the following subsections:

- *__Given conditions__* that were obtained from a self propulsion report [Baranowski 2005], including ship data with constraints, resistance and power prediction data for minimum required propulsion efficiency, sea trial propulsion data for minimum thrust requirement and maximum allowable torque requirement;

- ***Base propeller geometry determination*** in terms of pitch and expanded area ratio that employs a classical B_P-δ design method with a Wageningen B4 type propeller of several expanded area ratios in terms of minimum required area based on cavitation;
- ***New base propeller determination*** that contains the method of determining the new base propeller, which is mainly a combination of the classical method with analysis in consideration of particular working conditions; and
- ***Optimization of the new base propeller*** that includes a brief introduction of the panel method code and optimization in terms of the variation of pitch values and distribution under the full scale cavitation number, with the hull effect and inflow wake that is surveyed and extrapolated for full scale. During optimization, the in-house panel method code *PROPELLA*, along with pre- and postprocessors were used.

Figures 1, 2 and 3 shows the full form diagram of the dual-semi-tunnel shallow water ice class ship, side view of the model ship and the propeller arrangement at the stern of the twin-propeller ship. The diameter of the full-scale propeller is limited to 1.60 meters.
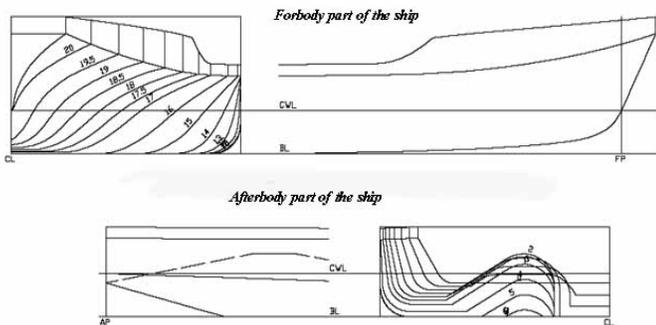

Figure 1. HULL FORM DIAGRAM OF THE DUAL-SEMI-TUNNEL SHALLOW WATER ICE CLASS SHIP.
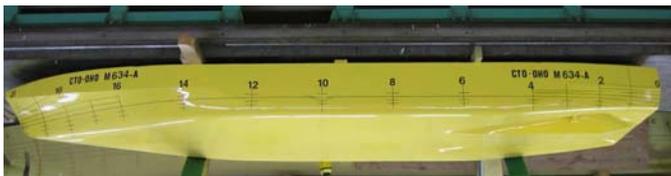
**Figure 2. A PICTURE OF THE SIDE VIEW OF THE MODEL SHIP.**
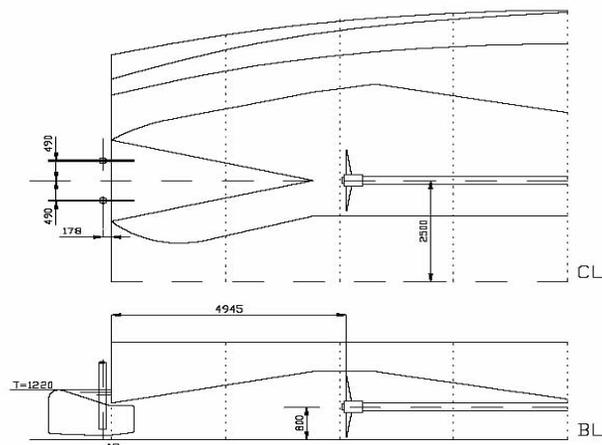
Figure 3. PROPELLER ARRANGEMENT AT THE STERN OF THE TWIN-PROPELLER SHIP.

Self Propulsion Propeller Data. These data are as follows:

- Propeller Model (s): P468 & P475
- Number of Blades   z: 4
- Propeller Diameter D: 1.60 m
- Pitch/D ratio at 0.7R: 1.1100
- Propeller revolution N: 449.50 (rpm)

FIGURE 4 SHOWS TWO DIFFERENT REAR VIEWS OF THE ICE BREAKER PROPULSION ARRANGEMENT.

Table 1 shows the self propulsion results for the hull with two stock propellers. Table 2 presents the extrapolated thrust and torque coefficients for full scale propeller.

Table 1. POWER PREDICTION FROM SELF PROPULSION TESTS.

SHIP Condition: Trials

V_S[kn]	P_{ES}[kW]	$2xP_{DS}$[kW]	n_S[rpm]	T_S[kW]	Q_S[kNm]	Fn_h
6	66	258	171.3	20	7	0.551
6.44	72	286	179.9	22	8	0.591
7.07	127	478	213	32	11	0.649
7.53	197	1561	316	78	24	0.691
8.05	328	4492	449.3	161	48	0.738
8.61	682	5042	467.2	176	52	0.79
9.04	1001	5055	467.2	176	52	0.829
10.02	1299	5059	467.6	176	52	0.92

Table 2. PROPULSION PERFORMANCE FROM SELF PROPULSION TESTS.

Table 2. PROPULSION PERFORMANCE FROM SELF PROPULSION TESTS.

Thrust Coefficient and Torque Coefficient for Full Scale Trials Condition (Sorted)

Vs [Kn]	Js Ship	Kts	Kqs	10Kqs	Efficiency
8.0500	0.3457	0.2193	0.0409	0.4087	0.2953
8.6100	0.3556	0.2217	0.0409	0.4094	0.3065
9.0400	0.3733	0.2217	0.0409	0.4094	0.3218
8.0500	0.4134	0.2213	0.0409	0.4087	0.3563
7.5300	0.4598	0.2148	0.0413	0.4131	0.3805
7.0700	0.6404	0.1940	0.0417	0.4167	0.4744
6.0000	0.6758	0.1874	0.0410	0.4100	0.4917
6.4400	0.6907	0.1869	0.0425	0.4248	0.4837

A classical Bp-δ diagram method was used to estimate the requirement of propulsive performance. Table 3 shows the estimated required thrusts and efficiencies at different ship speeds.

Table 3. REQUIRED PROPULSIVE PERFORMANCE AT DIFFERENT SPEEDS.

Propeller Diameter in m		1.60				
Revolution Speed in rpm		449.50				
Fluid Density in Tonne/m^3		1.0250				
Delivered Power for each Propeller (KW)		859.00				
Effective Power for each propeller (KW)	102.00	100.00	112.50	101.00	101.50	102.50
Ship Speed in knot	7.60	7.5300	7.8000	7.5600	7.5800	7.6200
Ship Speed in m/s	3.91	3.8742	4.0131	3.8896	3.8999	3.9205
Propeller Advance Speed	4.20	4.0292	4.7286	4.1074	4.1543	4.2509
Ship Advance Coef., J_s	0.3262	0.3232	0.3348	0.3245	0.3254	0.3271
Wake Fraction, W_s	-0.0747	-0.0400	-0.1783	-0.0560	-0.0652	-0.0843
Thrust Deduction Fraction, t	0.6982	0.6740	0.7409	0.6865	0.6925	0.7037
Propeller Advance Coefficient, J_p	0.3506	0.3361	0.3945	0.3427	0.3466	0.3546
Required Resistance, R=Pe/Vs in KN	52.17	51.62	56.07	51.93	52.05	52.29
Required Thrust for each Propeller, T in KN, Pe=T*Va	86.445	79.178	108.18	82.84	84.64	88.24
Required Kt for each propeller	0.229	0.2100	0.2869	0.2197	0.2245	0.2340
Required Torque for each Propeller, Q in KN-m, Pd=2*PI*n*Q	18.24	18.24	18.24	18.24	18.24	18.24
Required Kq for each propeller	0.0303	0.0303	0.0303	0.0303	0.0303	0.0303
Required Propeller Efficiency, η	0.4229	0.3714	0.5955	0.3961	0.4094	0.4366

Table 3 reveals that to achieve a speed of 7.6 knots, the propeller should have an efficiency of 0.4229 or higher, a thrust coefficient of 0.2293 or higher and a torque coefficient of 0.0303 or lower, according to the thrust power prediction curve for the ship hull obtained from the self propulsion test and the fixed value of the single engineer delivered power.

Wake Survey. Wake survey data was provided in the self propulsion tests report. Equivalent ship wake fraction, thrust deduction fraction and relative rotational efficiency were then obtained. Figure 5 shows the axial wake in the propeller plane, view from the stern.
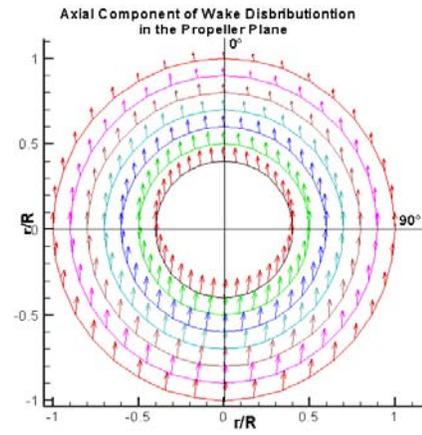

Figure 5. AXIAL WAKE DISTRIBUTIONS IN THE PROPELLER PLANE

Figure 6 shows the circumferential distribution of the axial wake in the form of input for the code, in terms of 1-Vx/Vm, where V_m is the model ship advance speed. Note that the horizontal axis of the figure is the vertical axis in ship, i.e., zero degree in the plot pointing at the North and the plot was viewing from bow and the circumferential positions were counted clockwise.
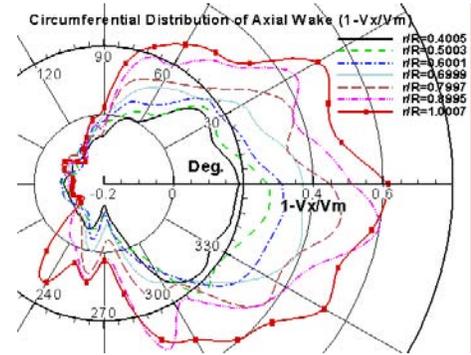

Figure 6. CIRCUMFERENTIAL DISTRIBUTION OF AXIAL WAKE IN THE FORM FOR THE CODE INPUT.

Figure 7 shows the normalized radial components of the wake. Due to the hull shape (semi-tunnel) at the propeller plane, the velocity profile is not perfectly symmetrical between the port and starboard side, but is obviously asymmetrical between near hull wall side (top) and bottom side.
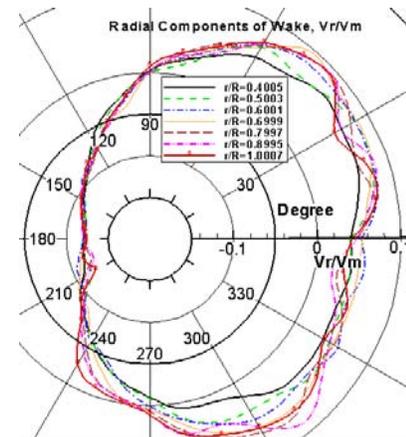

Figure 7. NORMALIZED RADIAL COMPONENTS OF THE WAKE.

Figure 8 shows the normalized tangential components of the wake in the propeller plane.
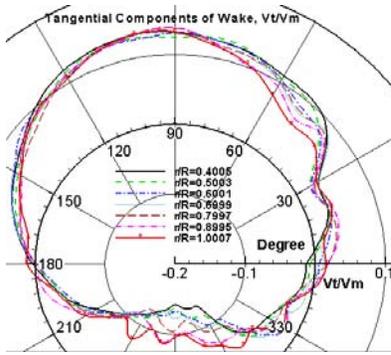

Figure 8. TANGENTIAL COMPONENTS OF THE WAKE IN THE PROPELLER PLANE.

For the propeller in the left semi-tunnel, a very strong asymmetry of the tangential velocity is shown between the mid-ship (90°) side and the port side (180°).

Base Propeller Determination

The number of blades and diameter of the propeller were fixed as a basic requirement for the base propeller determination. The classic B_P-δ design method with a Wageningen B4 propeller of several expanded area ratios in terms of cavitation performance were used to make decision about the particulars of the base propeller. Table 8 presents the preliminary of particulars. In calculations, the diameter of propeller, shaft revolution speed and engine output power (shaft torque limit) are fixed.

Performance Estimation. Table 4 shows the procedure that determines the base propeller, using the traditional methods.

Based on the given fixed number of blades and diameter, at constant rotational speed and delivered power, the maximum reachable speed for a B4-55, -70 and -85 propeller was around 7.57, 7.56 and 7.53 knots, respectively. The target was to achieve 7.6 knots or more satisfying all the given operating conditions. Therefore, a new propeller must be designed and optimized to exceed the performance of these B-series propellers.

Table 4. DETERMINATION OF THE BASE PROPELLER BASED ON B-SERIES.

Constant power and rpm for B4-55

P_d	Delivered power (Emperor HP)	1167.35	1167.35	1167.35	1167.35
V_s	Knot	7.07	7.53	7.60	8.05
W_s	Wake fraction	0.12	-0.04	-0.07	-0.33
t	Thrust deduction	0.46	0.67	0.70	0.75
J	Ship advance coefficient	0.30	0.32	0.33	0.35
V_a	Knot	6.23	7.83	8.16	10.71
J_p	Propeller disk advance coefficient	0.27	0.34	0.35	0.46
Pitch ratio	From Bp-Delta diagram	0.77	0.79	0.81	0.82
η_o	Propeller efficiency	0.35	0.42	0.43	0.53
η_h	Hull efficiency	0.62	0.31	0.28	0.18
η_r	Relative rotation efficiency	0.88	0.94	0.94	0.95
η_{total}	Total efficiency	0.19	0.12	0.11	0.09
P_e	thrust power=P_d* η_o* η_h * η_r (KW)	164.45	106.42	98.48	80.19
P_e	Pe (English HP)	223.74	144.78	133.99	109.10
Thrust	Kg	5236.31	2695.07	2392.42	1485.47
Thrust	KN	51.32	26.42	23.45	14.56

Constant power and rpm for B4-70

Pitch ratio	From Bp-Delta diagram	0.79	0.82	0.84	0.85
η_o	Propeller efficiency	0.34	0.41	0.43	0.51
η_h	Hull efficiency	0.62	0.31	0.28	0.18
η_r	Relative rotation efficiency	0.94	0.94	0.94	0.94
η_{total}	Total efficiency	0.20	0.12	0.11	0.09
P_e	thrust power=P_d* η_o* η_h * η_r (KW)	169.27	103.43	97.94	75.92
P_e	Pe (English HP)	230.30	140.72	133.25	103.29
Thrust	Kg	5389.93	2619.50	2379.23	1406.32
Thrust	KN	52.82	25.67	23.32	13.78

Constant power and rpm for B4-85

Pitch ratio	From Bp-Delta diagram	0.74	0.83	0.84	0.85
η_o	Propeller efficiency	0.33	0.40	0.42	0.50
η_h	Hull efficiency	0.62	0.31	0.28	0.18
η_r	Relative rotation efficiency	0.94	0.94	0.94	0.94
η_{total}	Total efficiency	0.19	0.12	0.11	0.09
P_e	thrust power=P_d* η_o* η_h * η_r (KW)	164.30	100.41	94.52	74.43
P_e	Pe (English HP)	223.53	136.61	128.60	101.26
Thrust	Kg	5231.40	2542.83	2296.24	1378.75
Thrust	kN	51.27	24.92	22.50	13.51

Figure 9 shows the required effective power versus ship speed and the thrust power capability of the B-series propellers with three different expanded area ratios (EAR).
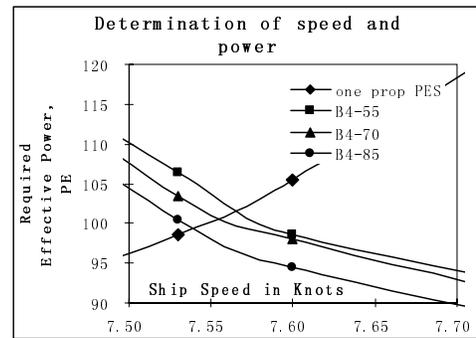

Figure 9. DETERMINATION OF SPEED AND POWER FOR THE BASE PROPELLER.

Determining the Minimum Required Expanded Area Ratio. The expanded area ratios are normally determined by the cavitation allowance. Using the classical Burrill's method, the required blade area based on cavitation for the ice class propeller CCGS Eckaloo is determined (intersection of the two lines) and shown in figure 10.
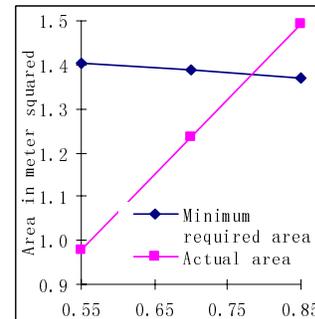

Figure 10. DETERMINATION OF MINIMUM REQUIRED AREA FOR HEAVILY LOADED PROPELLER.

4

With the target speed of 7.6 knots, the expanded area ratio EAR is EAR=0.7919 (the intersection of the two curves in Figure 10) and P/D=0.83. In this case, the equivalent propeller open water advance coefficient is J=0.33 based on the estimated wake fraction factor from the self propulsion tests. Cavitation number based on the formula in the current version of the code is then:

$$\frac{P_{atm} + \rho g(H-R) - P_{vapor}}{0.5\rho n^2 D^2} = \frac{101300 + 1000 \times 9.8 \times (1.22 - 0.8) - 1730}{0.5 \times 1000 \times (449.5/60)^2 1.6^2} = 1.4433 \text{ , and}$$

cavitation number based on classical references/chart calculation:

$$\frac{P_{atm} + \rho g(H-R) - P_{vapor}}{0.5\rho n^2 D^2} = \frac{101300 + 1000 \times 9.8 \times (1.22 - 0.8) - 1730}{0.5 \times 1000 \times [0.7\pi(449.5/60)^2 1.6^2 + V_a^2]} = 0.2985$$

Strength Validation for the Base Propeller. With the maximum thickness at r/R=0.0 and 1.0 of t_{max} = 137.8 mm = 0.0861 D and t_{max} = 7.88 mm = 0.0049D, respectively, chord length at 0.2 R of 0.512 m, rake angle of 12 degrees, number of blades of 4, diameter of the propeller of 1.6 m, shaft speed of 449.5 rpm, delivered power 1175 HP and ice class III propeller thickness correction, it gives the blade thickness distribution in table 6.

Table 5. MODIFIED THICKNESS DISTRIBUTION FOR THE BASE PROPELLER.

r/R	t/D	t/c
0.0000	0.1124	
0.2000	0.0870	
0.3000	0.0749	0.2018
0.4000	0.0635	0.1533
0.5000	0.0530	0.1179
0.6000	0.0430	0.0912
0.7000	0.0338	0.0715
0.8000	0.0251	0.0564
0.9000	0.0168	0.0455
0.9500	0.0129	0.0454
1.0000	0.0090	0.0552

New Base Propeller Determination

As mentioned in the previous subsection, the base propeller cannot reach the required propulsive performance to get the ship at a speed of 7.6 knots. The base propeller has to be modified. An NACA 66 MOD sectional geometry with a mean line of A=0.8 was chosen. If this sectional type cannot still satisfy the propulsion performance, a more detailed modification on the individual section is then necessary.

The planform shape of the new base propeller is designed based on the PP0000C0 propeller model, which is a base propeller for a podded propeller series [Liu 2002A]. With a consideration of the tunnel effect, that is similar to a propeller with a nozzle, a much wider blade tip was taken. The nominal pitch at 0.7R is 0.83 as shown in table 7 for the planform shape arrangement.

Table 6. PLANFORM GEOMETRY DETAILS OF THE PROPELLER.

Sectional Geometry Offsets for new ice class propeller based on PP0000C0 in the Radial Direction				
r/R	c/d	p/d	t/c	f/c
0.3000	0.3712	0.8300	0.1553	0.0232
0.4000	0.4145	0.8300	0.1180	0.0230
0.5000	0.4498	0.8300	0.0916	0.0218
0.6000	0.4721	0.8300	0.0696	0.0207
0.7000	0.4733	0.8300	0.0542	0.0200
0.8000	0.4452	0.8300	0.0421	0.0197
0.9000	0.3700	0.8300	0.0332	0.0182
0.9500	0.2842	0.8300	0.0323	0.0163
1.0000	0.1638	0.8300	0.0316	0.0118

A rake of 12 degrees was chosen to improve the inflow of the propeller. The hub diameter ratio for this type of ice class propeller was taken as 0.26 with zero skew.

Optimization of the New Base Propeller

Propeller performance was estimated with the variation of pitch value and distributions. Figure 11 shows the various pitch values and distributions in the optimization.
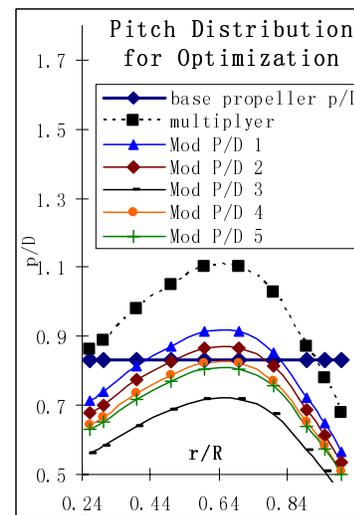

Figure 11. VARIOUS PITCH DISTRIBUTIONS USED IN THE PROCESS OF OPTIMIZATION.

Use of Numerical Code for Optimization. A comprehensive software package, *PROPELLA* was extensively used for the optimization work [Liu 1997, Liu and Bose 1998, and Liu 2002B]. *PROPELLA* is a three-dimensional, unsteady panel method code for the evaluation of propeller thrust and torque (shaft and blade torque/bending moments) and for the design and optimization of a prototype propeller. This software package has the ability to model ducts and rudders and other arbitrary bodies in the vicinity of the propeller, with/without inflow wake. *PROPELLA* has been validated against published data for a range of propeller types, including B-series, a number of ice class propeller and Kaplan as well as highly skewed models. *PROPELLA* enables the user to visualize the pressure distribution over the propeller blade and hub, and to examine loads and sheet cavitation areas on a per-blade basis. This capability is useful in examining cyclic loading due to wake characteristics or flow blockages

There are 24 runs to complete the computation for the propeller with 1.60 m diameter. These runs include the five runs of different pitching values and distributions at the design advance coefficient, J=0.33. Four additional runs to study the effects of rake angle on propulsive performance at design J and optimized pitch distributions. Some additional runs were also performed to study the hull effect, cavitation effect and inflow wake effect for all the pitch distributions.

5

Summary of the Optimized Propeller. Propulsive performance of the 3 different pitch values (2 pitch values are not show) is shown in figure 12. In the figure, the straight lines are required minimum thrust coefficient, Kt for 7.6 knots, maximum allowable torque coefficient, Ka (limited power consumption), and minimum required efficiency, η.

For the three curves, Kt, Kq and η, to intersect at about the same nominal pitch value, it requires substantial more computational runs. A pitch value of 0.87 satisfies all three required minimum values.
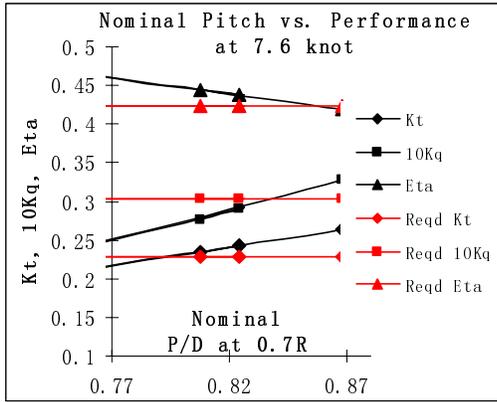

Figure 12. NOMINAL PITCH VALUES VERSUS PROPULSIVE PERFORMANCE FOR 1.6M DIAMETER PROPELLER.

Pitch distribution 4 was selected primarily as it satisfies the required thrust and efficiency at J=0.33 (7.56 knots). Further simulations have been performed at higher advance coefficients (at higher propeller advance speed), which marginally satisfy required thrust and efficiency conditions. Finally at J=0.3546 (7.62 knots) was achieved. The finalized particulars of the optimized propeller are summered in tables 8, 9 and 10, for information on general parameters, planform profile and sectional offsets, respectively.

Table 7. OPTIMIZED PROPELLER GEOMETRY PARAMETERS.

Propeller Diameter, D	1.6	m
Expand Area Ratio, EAR	0.7919	
Number of Blades	4	
Rotational Speed	449.5	rpm
Pitch Distribution		
r/R=0.26	0.6442	D
r/R=0.7	0.824	D
r/R=1.0	0.5094	D
Hub Diameter Ratio	0.26	D
Max. Thickness Ratios		
r/R=0.0	0.1124	D
r/R=0.2	0.0870	D
r/R=0.9	0.0168	D
r/R=1.0	0.009	D
Equivalent flow conditions in classical propeller Design		
Design Advance Speed (knots)	7.62	
Wake Fraction, Ws	0.0843	
Thrust Deduction, t	0.7037	
Design Advance Coefficient J	0.3546	

Table 8. PROPELLER PLANFORM PROFILE DETAILS.

r/R	c/D	p/D	Skew	Rake
0.30	0.3712	0.6667	0.0000	0.2125
0.40	0.4145	0.7341	0.0000	0.2125
0.50	0.4498	0.7865	0.0000	0.2125
0.60	0.4721	0.8240	0.0000	0.2125
0.70	0.4733	0.8240	0.0000	0.2125
0.80	0.4452	0.7720	0.0000	0.2125
0.90	0.3700	0.6517	0.0000	0.2125
0.95	0.3300	0.5843	0.0000	0.2125
1.00	0.2842	0.5094	0.0000	0.2125

Table 9. PROPELLER SECTIONAL OFFSET PROFILE DETAILS.

r/R	t/c	f/c	t (mm)	f (mm)
0.30	0.2018	0.0232	119.8631	13.76707
0.40	0.1533	0.0230	101.6507	15.2735
0.50	0.1179	0.0218	84.82861	15.70342
0.60	0.0912	0.0207	68.85859	15.65106
0.70	0.0715	0.0200	54.13741	15.16832
0.80	0.0564	0.0197	40.17429	14.01133
0.90	0.0455	0.0182	26.95007	10.75664
0.95	0.0454	0.0163	23.98097	8.61168
1.00	0.0552	0.0118	25.11066	5.34296

As the propeller will be working under very heavy load condition, root and tip cavitation and could be problematic. We reduced the pitch values of blade root and tip to 78% (0.6442/0.8420) and 62%, respectively. Figure 13 shows the mesh view generated and panelized by *PROPELLA* for computation.
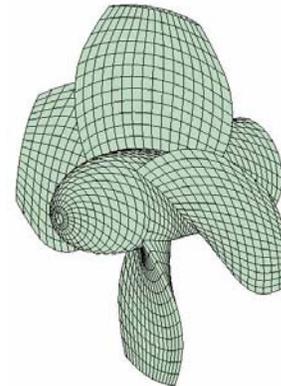

Figure 13. SURFACE VIEW OF THE OPTIMIZED PROPELLER.

During computations, the hull gap effect, i.e., nozzle effect was taken in to account by including the region of the hull around the propeller. Figures 14 and 15 are the rear and bottom view of the propeller-hull interaction mesh.
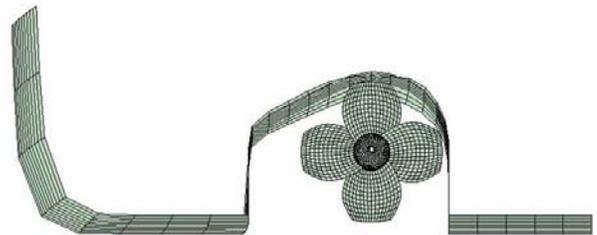
**Figure 14. PROPELLER-HULL ARRANGEMENTS VIEWING FROM STERN TO BOW.**

6
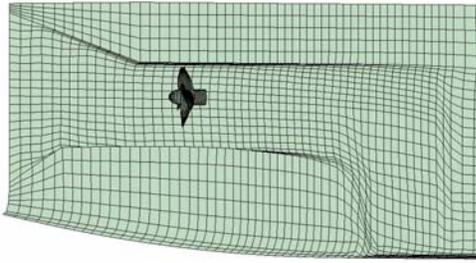
Figure 15. BOTTOM VIEW OF THE PORT PROPELLER IN THE SEMI-TUNNEL UNDER A REAR PART OF THE HALF HULL.

Figure 16 is the rear view of the propeller inside the semi-tunnel.
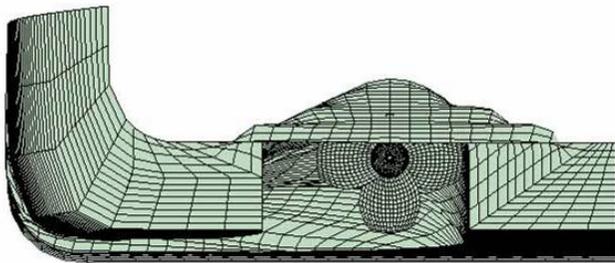
Figure 16. REAR VIEW OF THE PORT PROPELLER IN THE SEMI-TUNNEL UNDER A REAR PART OF THE HALF HULL.

Hydrodynamic characteristics of the Optimized Propeller. Figure 17 shows Kt and Kq fluctuations over one revolution (zero degree of key blade is pointing north, going in clockwise direction), at an advance coefficient of J=0.3546 (Speed of propeller shaft V_a = 7.62 knots).
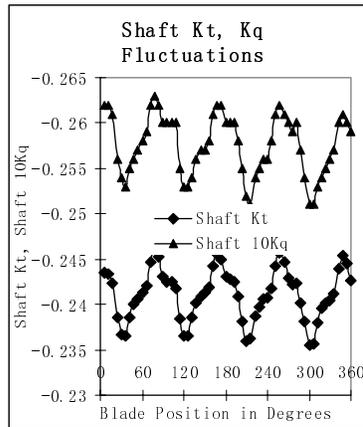

Figure 17. SHAFT THRUST AND TORQUE COEFFICIENTS FLUCTUATIONS OVER ONE PROPELLER ROTATION.

It can be seen that at 90 degrees, when a blade is at horizontal position pointing at the centre line of the ship, i.e., aiming at the other propeller, the shaft torque and thrust reached maximum. However, compared with the torque and thrust at other positions, they do not have large enough fluctuation to create a vibration problem.

Figure 18 shows the pressure coefficient before and after cavitation correction for blade section at 0.72R at 0°, 90°, 180° and 270° of key blade location
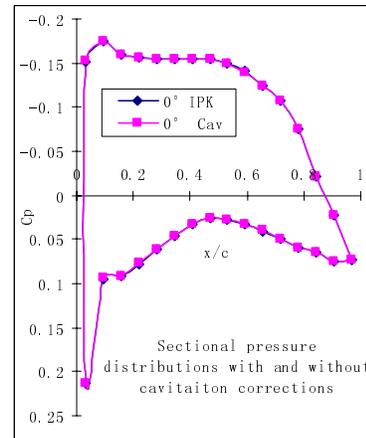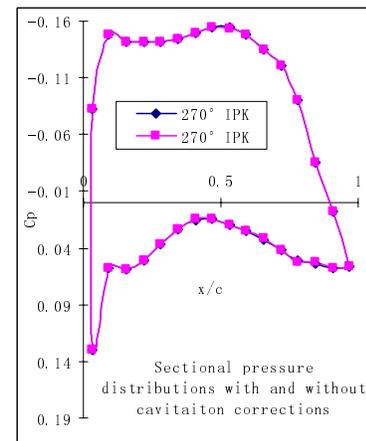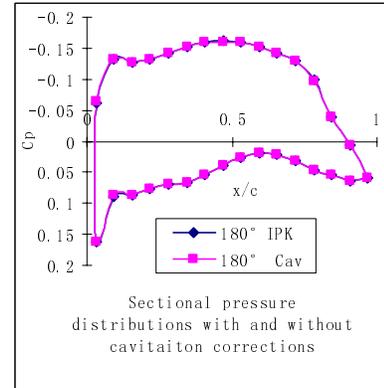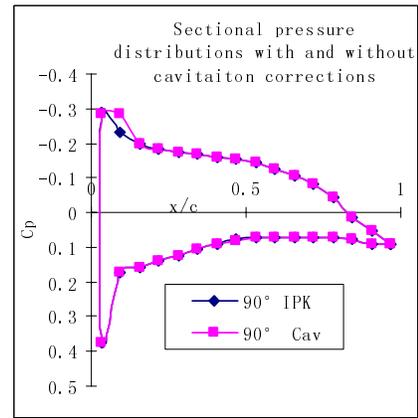

Figure 18. PRESSURE COEFFICIENTS BEFORE AND AFTER CAVITATION CORRECTION.

When the key blade is pointing at the mid-ship position, it has the maximum negative pressure with a little cavitation at the leading edge (top left plot).

Effect of Presence of Inflow Wake. Figure 19 shows the performance comparison of the optimized propeller working in the wake of tunnel hull and working in the open water for various pitch distributions at J=0.33 and n=7.5 rps.

It can be seen that with inflow wake taken in to account the propeller gave a better propulsive performance in terms of efficiency, with both increased thrust and torque. At the propeller disk plan inside the semi tunnel top, inflow axial velocity is increased. The equivalent wake fraction calculated using the wake survey of the ship was negative (-0.0747 at 7.6 Kts), apposite to a positive value for traditional single propeller hull ships.

This increased efficiency, however, did not give good overall ship hull efficiency as the thrust deduction of the ship is very large (0.6982 at 7.6 Kts), due to a very complicated stern shape.
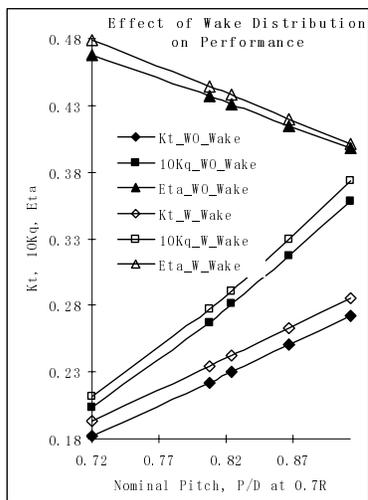
Figure 19. PERFORMANCE COMPARISON OF THE OPTIMIZED PROPELLER.

Effect of Presence of Tunnel Gap. Figure 20 shows the comparison of the propeller with and without tunnel gap effect, with a variation of pitch distributions at J=0.33 and n=7.5 rps.
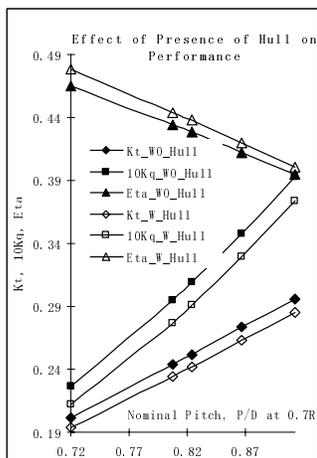
Figure 20. COMPARISON OF THE PROPELLER WITH AND WITHOUT TUNNEL GAP EFFECT.

From the figure it noted that the tunnel gap has a decrease in thrust with a more drop in torque, giving a resultantly higher efficiency. This is similar to the nature of nozzle propellers.

CONCLUSION

A design and optimization procedure developed and used for a propeller installed on a twin-semi-tunnel-hull ship navigating in very shallow and icy water under heavy load conditions is presented. This novel and practical design and optimization procedure is a combination of the base propeller determination using classical design method and the detailed optimization using hydrodynamic code. The procedure described here is suitable for both special purpose propellers and conventional propellers design. A panel method code (*PROPELLA*) was used to vary the pitch values and distributions and take into account the inflow wake distribution, tunnel gap and cavitation effects. The methodology developed was then applied on a very shallow water semi-tunnel ship with two propellers navigating in an icy water environment. The optimized propeller was able to numerically achieve a ship speed 0.02 knots higher than the desired speed and 0.06 knots higher than the classical B-series propeller. Further optimization may also be performed by modifying the blade sectional profile and pressure distribution for cavitation, when special performance characteristics are need. For the ice class, shallow water propeller, the analysis of the effect of inflow wake and tunnel gap on propulsive performance was presented. The results showed that a slight peak torque and thrust increase is seen when a blade is horizontal pointing at the other propeller (centre-line plane), compared with other positions, which means the optimized propeller has a reasonably small shaft force fluctuation. The pressure coefficient at 0.7R was presented at 4 different circumferential positions over one revolution and showed that the highest negative pressure coincided with the position where the torques and thrusts were at maximum. At that position, a very small cavitation occurred at the leading edge. The inflow wake has a positive effect on the efficiency duo to the increase of the thrust more than the increase of the torque. This is mainly due to the hull wall effect in terms of the tunnel. The presence of the tunnel also showed a similar effect to nozzle on a propeller. With the presence of the hull, the propeller produced thrust dropped but with a larger decreased torque requirement. This in combination gave an increased efficiency.

ACKNOWLEDGEMENT

REFERENCES

[1] Hess, J.L. and Valarezo, W.O., 1985. "Calculation of steady flow about propellers by means of surface panel method". *Proceedings, Research and Technology Douglas Aircraft Company*, Long Beach, CA, 8p.

[2] J. E. Kerwin and C-S Lee, 1978. "Prediction of steady and Unsteady Marine propeller performance by Numerical Lifting Surface Theory". *SNAME Transaction*, Vol 86, 1978, pp. 218-253.

[3] J. M. Hotaling, J. M. Meehan and G. Karafiath, 2001. "Fisheries research vessel hull and propeller design to maximize hydro acoustic survey efficiency". *U.S. Papers for 24th UJNR/MFP*, 18 p.

[4] G. Bertaglia, G. Lavini and S. Scarpa, 2004. "Hull design and optimization with pod propellers with 5 and 6 blades". *Proceedings of the 1st International Conference on Technological Advances in Podded Propulsion*, University of Newcastle, Newcastle, UK, pp. 39-57.

[5] A. Baranowski, 2005. *CCGS Eckaloo results of model tests in shallow water hull model M634-A: resistance, self propulsion and wake 3D.* Ship Design and Research Centre Technical Report, No. RH-2005/T-053E, Gdansk, Poland, 51 p.

[6] P. Liu, 2002A. *Geometrical Design of a Podded Propeller Base Mode.* Design Notes, National Research Council Canada, Institute for Ocean Technology. 3p.

[7] P. Liu, 1996. *Software Development on Propeller Geometry Input Processing and Panel Method Predictions of Propulsive Performance of the R-Class Propeller.* MMC Engineering & Research Report, NL Canada, 50 p.

[8] P. Liu and N. Bose, 1998. "An Unsteady Panel Method for Highly Skewed Propellers in Non-Uniform Inflow". *22nd ITTC Propulsion Committee Propeller RANS/Panel Method Workshop*, 5-6 April, Grenoble, France, pp.343-349.

[9] P. Liu, 2002B. "Design and implementation for 3-D unsteady data visualization using object-oriented MFC and OpenGL", *International Journal of Computational Fluid Dynamics of Japan*, Vol. 11, no. 3, pp. 335-345.