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PROPELLA: A NUMERICAL TOOL TO STUDY VARIOUS ASPECTS OF PODDED PROPULSORS

Mohammed F Islam[1], Pengfei Liu[2] and Brian Veitch[3]

[1]Doctoral Candidate, Faculty of Engineering and Applied Science, Memorial University of Newfoundland, St. John's, NL A1B 3X5, Canada, Tel.: +1-709-743-5627, E-mail: islam@engr.mun.ca, [2]Senior Research Officer, Institute for Ocean Technology (IOT), National Research Council, St. John's, NL A1B 3T5, Canada, [3]Professor, Faculty of Engineering and Applied Science, Memorial University of Newfoundland, St. John's, NL A1B 3X5, Canada.

Abstract

This paper describes the numerical aspects of a research program on podded propulsors, which is being undertaken jointly by the Ocean Engineering Research Centre at Memorial University of Newfoundland, the National Research Council's Institute for Ocean Technology, Oceanic Consulting Corporation, and Thordon Bearings Ltd. The numerical tool is an in-house panel method code, PROPELLA. The code is a low order source-doublet, steady/unsteady time domain panel method code having capabilities to predict hydrodynamic performance of screw propellers with various configurations. Under the research program, the code was extended and used to model the propellers, pod-strut combinations and strut-wake impingement model. Amongst the hydrodynamic issues that have been addressed through numerical predictions were questions regarding the effects of hub taper angle (propeller only case and pod-strut-propeller case), pod-strut configuration (push and pull), geometric variations, azimuthing conditions and pod-strut interactions (wake impingement effect) on podded propeller performance. Predictions were made both in pusher and puller configurations for the pods and reasonable agreement was achieved between the predictions and measurements. The code is being modified to study the podded propulsors' performance at static and dynamic azimuthing conditions. The code is also capable of performing simulations with propellers and bodies like ship hull, underwater vehicles with fins.

Keywords: Podded propulsors, pusher and puller configurations, panel method, propulsive performance, hub taper angle, propeller-ice interaction.

NOMENCLATURE

T	Temperature (°)
D	Propeller diameter (m)
R	Propeller radius (m)
n	Propeller rotational speed (rps)
V_A	Propeller advance speed, in the direction of carriage motion (m/s)
T_{Prop}	Propeller thrust (N)
Q	Propeller torque (Nm)
T_{Unit}	Unit thrust (N)
$K_{T\text{Prop}}$	Propeller thrust coeff., $T_{\text{Prop}} / \rho n^2 D^4$
$10K_Q$	Propeller torque coeff., $10Q / \rho n^2 D^5$
$K_{T\text{Unit}}$	Unit thrust coefficient, $T_{\text{Unit}} / \rho n^2 D^4$
J	Propeller advance coeff., V_A / nD
η_{Prop}	Propeller efficiency, $J / 2\pi \times (K_{T\text{Prop}} / K_Q)$
η_{Unit}	Unit efficiency, $J / 2\pi \times (K_{T\text{Unit}} / K_Q)$

1. Introduction

The podded propulsion system is a modern ship propulsion concept. *Fig.* 1 shows a schematic view of the major components of a typical podded propulsion system. The pod propulsion systems have proven to be an attractive propulsion system for ship owners in past due to the improved maneuvering performance.

Basically, two types of pod propulsion system are used in the marine industry, namely, pusher pod propulsion system and puller pod propulsion system. In a pusher system, the propeller is attached to the after end of the pod, thus the propeller pushes the unit. In a puller (also termed as tractor) pod propulsion system the propeller is attached to the fore end of the pod, thus the propeller pulls the unit. There are also other types of podded propulsors such as contra-rotating, propeller in tandem and hybrid. In a contra-rotating podded propulsion system, two propellers are attached to the same end of the pod shell and rotate in the opposite directions. In a tandem type podded propulsion system, two propellers are fitted at the two ends of the pod shell and rotate in the same directions. In a hybrid propulsion system, a puller podded propulsor is fitted with a conventional propeller. The various configurations of podded propulsors are shown in *Fig.* 2.

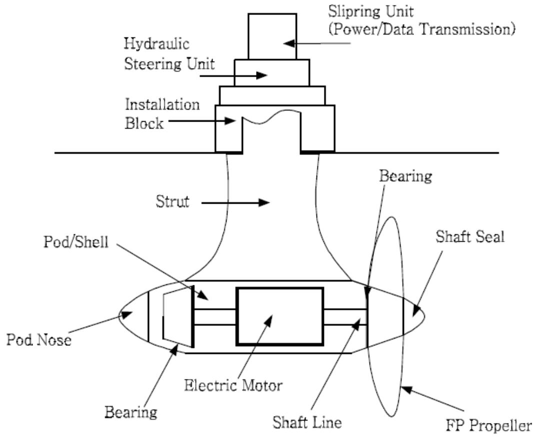

Fig. 1: A schematic diagram of podded propulsors showing all major components of this system.

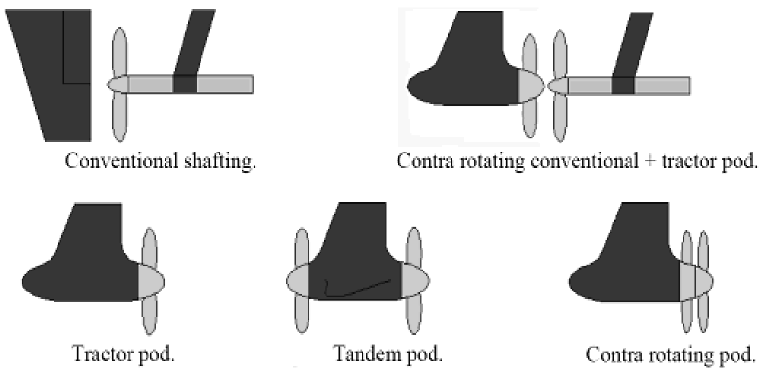

Fig. 2: Podded propulsor arrangements.

While considerable experimental work has been performed on podded propulsion over the last two decades, there is relatively little work on the hydrodynamic performance using numerical methods, such as panel and viscous flow methods. The numerical methods used to model and predict the performance is primarily the potential flow (panel) method.

An early application of the potential flow method to predict the hydrodynamic performance of hull forms with podded propulsors is presented by Cheng *et al.* (1989). In the paper by Kawakita *et al.* (1994), the authors presented a surface panel method to analyze the hydrodynamic performance of a hydrofoil system consisting of hydro-foil, strut and pod configuration. Szantyr (2001) presented a surface panel method calculation of hydrodynamic analysis of podded propulsor performance with validations. Han *et al.* (2000) used a potential-based panel method to solve the flow around the pod configuration including strut and fins and a vortex lattice method to solve the flow around the propeller. Paik *et al.* (2002) used a similar model to study a contra-rotating podded propeller and obtained better agreement with measurements for moderately loaded conditions. Kim and Kim (2001) also made a similar study for tractor and pusher type podded propellers, but they used only a panel method for the computation. Funeno (2003) described hydrodynamic development of the KHI's podded propulsion system where the geometry of the pod and the strut had been optimized by means of a numerical simulation technique based on the commercial Computational Fluid Dynamics (CFD) software STAR-CD. Sánchez-Caja and Pylkkanen (2004) presented a paper that deals with the optimization process of the propeller housing using a RANS solver FINFLO. Junglewitz *et al.* (2004a) presented calculations for steering forces and moments using an unsteady RANS code. Among the other numerical work on podded propulsors, Junglewitz *et al.* (2004b), Ohashi and Hino (2004), Chicherin *et al.* (2004), Deniset (2004) and Di Felice *et al.* (2004) are noteworthy.

Our research program entitled "Systematic Investigation of Azimuthing Podded Propeller Performance" combines parallel developments in numerical prediction methods and experimental evaluation. The work addresses gaps in the knowledge concerning podded propeller performance, performance prediction, and performance evaluation.

Amongst the hydrodynamic issues that have been addressed through numerical predictions were questions regarding the effects of hub taper angle (propeller only case and pod-strut-propeller case), pod-strut configuration (push and pull), geometric variations, azimuthing conditions and pod-strut interactions (wake impingement effect) on podded propeller performance. The current paper presents a few applications of the numerical tool, *PROPELLA* in predicting the performance characteristics of podded propulsors in various configurations.

2. Panel Method Code: *PROPELLA*

The panel method code, *PROPELLA*, is a low order source-doublet, steady/unsteady time domain panel method code having capabilities to predict hydrodynamic performance of screw propellers with various configurations. Constant sources and doublets are uniformly distributed over flat quadrilateral panels used to discretize simpler propeller geometry. Similar singularity distributions were used over hyperboloidal panels, which were used to discretize complex propeller geometry (highly skewed propeller). Constant doublets were distributed uniformly over flat quadrilateral panels to model propeller shed wake. Interaction effects among different bodies (i.e. propeller and nozzle or nozzle and rudder), between a body and wake and between body and induced velocities all are taken into account (Liu 1996). The structure, functionalities, implementation and demonstration of the code are discussed in detail in Liu (2008). In the following section a brief discussion of the structure and functionalities of the original code is given.

2.1 Functionality of *PROPELLA*

PROPELLA is an in-house software package designed to aid marine propeller research, creative design and manufacturing. The main functionalities of *PROPELLA* are to predict hydrodynamic forces and their induced structural dynamic forces. These include:

- Instantaneous and mean pressure distribution on the blade, nozzle, pod-strut, rudder and other arbitrary surfaces;
- Instantaneous and mean shaft thrust and torque, which are essential for marine propeller design;
- Blade in-plane, out-of-plane bending moments and blade spindle torque; and
- Shaft transversal forces such as vertical, horizontal forces and their resultant.

2.2 Structure of *PROPELLA*

PROPELLA consists of four major components. They are:

- Geometry and motion parameter input file generator INPUT, an ASCII text file;
- Propeller surface mesh generator;
- Pre- and post-processor, and
- Hydrodynamic numerical kernel.

The fourth component, the numerical kernel, employs a constant doublet/source, unsteady panel method in the time domain. This code is equipped with:

- An advanced iterative, dense, asymmetrical matrix solver, the Bi-Conjugate Gradient Stability (BiCGSTAB) method;
- A numerical iterative pressure Kutta (IPK) condition procedure formulated by a modified Newton-Raphson non-linear iteration scheme, the Broyden iteration;
- A low order quadrilateral/triangle kernel to obtain the influence coefficients;
- An optional hyperboloidal kernel to find the influence coefficients for the twisted panels that appear in the tip region of the blade; and
- A semi-empirical scheme that models chop-off and fill-in pressure for K_T and K_Q of a propeller under cavitation.
- A vortex-wake roll-up model with iteration.
- Force and torque prediction modules to predict 6-degree-freedom forces/moments at any panel centroid for forces and any described line for torques on the propeller surface.

3. Validation of the Code: *PROPELLA*

The code has been validated for more than a dozen propellers in terms of hydrodynamic properties since its development about a decade ago (Liu and Bose 1998). *Fig.* 3 shows a few propeller combinations that were studied using *PROPELLA*. In the current study, the extended code was used to produce numerical results first. The numerical results were then compared with the measurements without tweaking the code. The measurements consist of open water tests of three propellers with the same design blade sections (except hub taper angle). The model propellers have hub taper angles of 15° and 20° for pusher configurations and –15° for puller configurations (see *Fig.* 4). *Figs.* 5 and 6 show comparisons of propeller open water performance between measurements and predictions for model propellers, Push+15 and Pull-15, respectively (Islam 2004, Islam *et al.* 2004 and Islam *et al.* 2006).

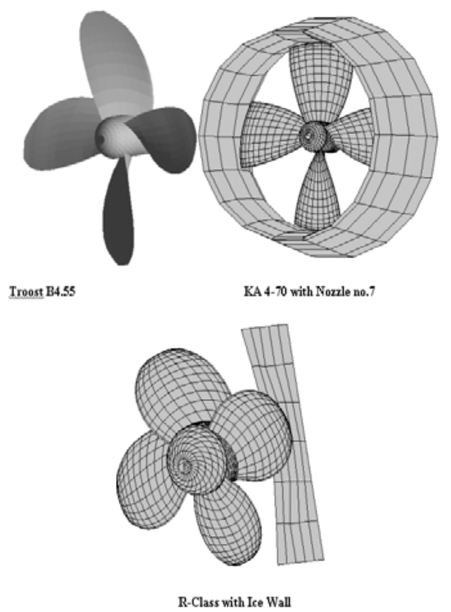

Fig. 3: A few propulsors studied using ***PROPELLA.***

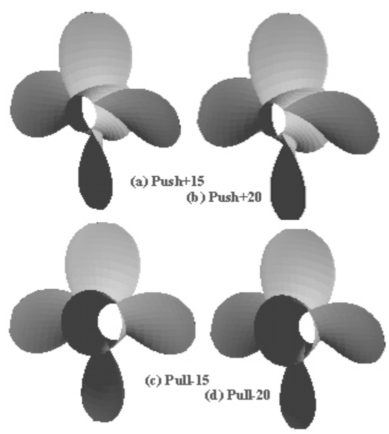

Fig. 4: Four model propellers (rendered model generated by PROPELLA). Fig. (a), (b), (c), (d) are the propellers with hub taper angles of +15° (push), +20° (push), -15° (pull), -20° (pull), respectively.

For the purpose of calculations, the simulation parameters that were used are summarized in Table 1. Table 2 summarizes the total number of simulations done for validation purposes. According to table 2, the total number of runs is 32 (so is the number of input files). In each run the executable needs one input file. All the runs were made using a batch process. The runs were performed in a Proliant (Compaq 82 ML570, 4xP3 700MHz Xeon w/512 cache with 4GB of RAM) server (Windows 2000 server operating system) and an Alpha ESXX server (DS20E, 2x667MHz with 4GB of RAM). On average it took around two hours for each run in both machines when the simulation parameters as indicated in Table 1 were used.

Table 1: List of parameters used in the code for the predictions of propeller performance.

Parameters	Push+15	Push+20	Pull-15	Pull-20	Straight Hub
Spanwise Grid Type	Uniform	Uniform	Uniform	Uniform	Uniform
Chordwise Grid Type	Uniform	Uniform	Uniform	Uniform	Uniform
No. of Spanwise Intervals (Blades)	12	12	12	12	12
No. of Chordwise Intervals (Blades)	16	16	16	16	16
Front hub cone length	1.7D	1.7D	1.25D	1.25D	1.00D
Rear hub cone length	3.0D	3.0D	3.0D	3.0D	1.00D
No. of axial intervals (Front hub)	8	8	6	6	6
No. of axial Intervals (Rear hub)	12	12	12	12	12
No. of circular intervals (Front hub)	24	24	24	24	24
No. of circular intervals (Rear hub)	24	24	24	24	24
No. of intervals between blades	6	6	6	6	6
Hub taper angle	15°	20°	-15°	-20°	0°
No of revolutions	3	3	3	3	3
Time steps per revolution	60	60	60	60	60

Table 2: Number of simulations performed for the validation of the extended code.

Simulation Parameters	Number of Simulations
Propeller Type	5 (2 pusher & 2 puller and 1 regular hub)
Advance Coefficient, *J*	9 (0.00-1.15)

It can be seen from *Figs*. 5 and 6 that predictions of open water propulsive performance are close to measurements for a wide range of advance coefficient. This is true both for the pusher and puller propellers. For K_T and K_Q, it is observed that the corresponding predicted values approach the measurements closely for a wide range of advance coefficient from the bollard pull condition (J=0.0) to an advance coefficient J = 1.0 (this covers most of the operating range of any practical propeller). In the case of the pusher propellers (*Fig*. 3), for an advance coefficient of close to zero (J = 0.0-0.2), the calculated values are very close to the measurements. For an advance coefficient of more than 1.0, the calculated values are slightly higher than the measurements. For a moderate advance coefficient range (J=0.20-0.80), the calculated values are slightly lower than the measurements. The predictions for the puller propeller, Pull-15, are closer to the corresponding measurements (see *Fig.* 6). In this case, the predicted values are lower than the measurements for high J values. The code is a potential flow code but a simplified empirical formulation was used to take into account the viscous effects in terms of skin friction. A more realistic formulation to take into account the viscous effects might improve the predictions further. The discrepancy between calculated and measured propeller efficiency as shown in *Figs.* 5 and 6 requires some comment. The wake roll-up and relaxation model (Liu 2002) was not enabled as it consumes too much CPU time and this might reduce thrust and torque at very high advance coefficients, which might give better comparison between the measured and predicted efficiency.

In a recent study the code was further validated for two propellers with two different pod-strut combinations taken from a series of 16 pods (Molloy *et al.* 2005). The validation consists of comparison of performance of the propeller measured at the propeller hub and of the unit measured as a whole. In calculating the effect of the pod-strut body on propeller performance, the effect of proximity of the pod-strut body (blockage effect) was considered. In other words, the influence of the panels of the pod-strut bodies on the propeller body was considered in calculating the performance. Interaction effects between the propeller and pod-strut body, the propeller wake and velocity induced by the pod-strut body and the propeller were all taken into consideration. The viscous wake was not modeled. The strut was not considered as a lifting body so the wake of the strut was not modeled.

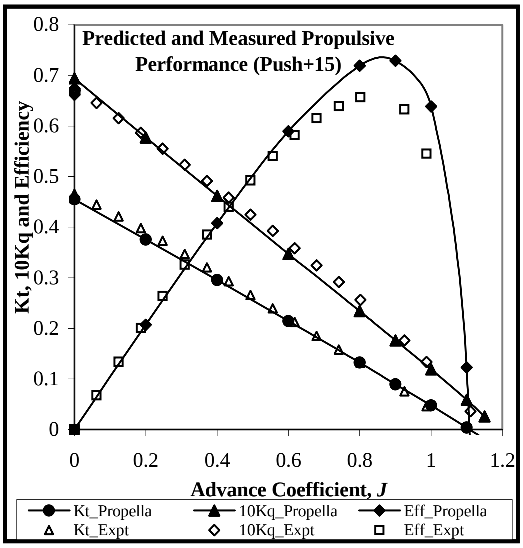

Fig. 5: Comparison of the measured (Expt.) and predicted (*PROPELLA*) propulsive characteristics of the model propeller, Push+15, with hub taper angle of 15° (push configuration).

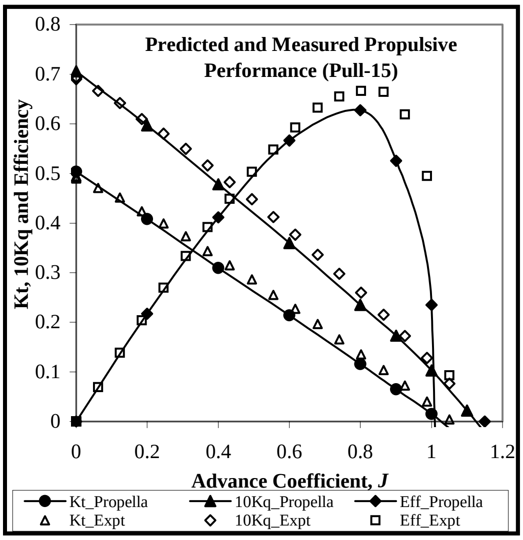

Fig. 6: Comparison of the measured (Expt.) and predicted (*PROPELLA*) propulsive characteristics of the model propeller, Pull-15, with hub taper angle of -15° (pull configuration).

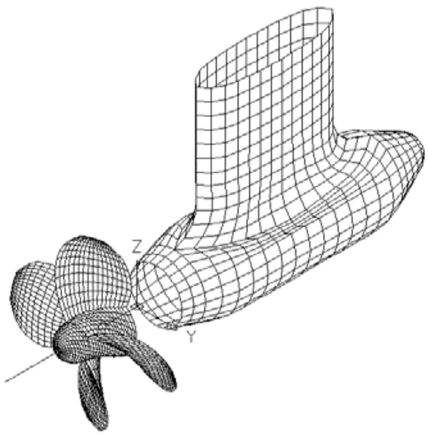

Fig. 7: Mesh view of the model propeller with pod-strut geometry in pusher configuration.

In pusher configuration, the propeller operates in the strut wake but this does not necessarily have a significant effect on the overall efficiency of the unit, since the wake extends over a small region of propeller disk. The effect of propeller wake on the strut in puller configuration (wake impingement effect) was not considered. In a recent study (He *et al.* 2005), it was found that the modified code that includes the wake impingement model does not register an appreciable effect on the prediction of the propeller performance. The various steps that were followed to include pod-strut geometry into the code are detailed in Islam (2004). *Fig.* 7 shows the mesh view of the model propeller with pod-strut geometry in pusher configuration. *Figs.* 8 and 9 show comparisons of propeller open water performance between measurements and predictions for the propeller-pod-strut systems, Pod #01. *Fig.* 8 shows the comparison between the predicted and measured propeller performance of the pod and *Fig.*

9 shows the comparison between the predicted and measured unit performance of the pod. It can be seen that the predicted value of propeller thrust is lower than the measurements for all advance coefficient values but the amount is reduced as the advance coefficient increases. The predicted value of propeller torque is slightly higher than the measurement at very low advance coefficient but slightly lower when the advance coefficient increases.

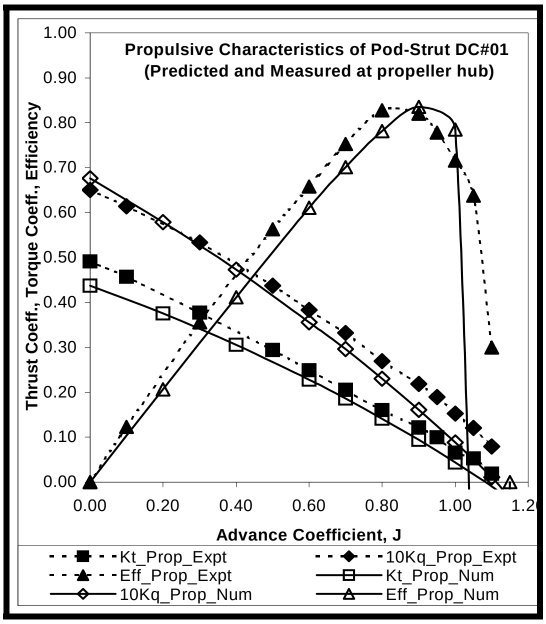

Fig. 8: Comparison of the measured (Expt.) and predicted (*PROPELLA*) propulsive characteristics of the propeller (measured at propeller shaft dynamometer) in Pod#01 in pull configuration.

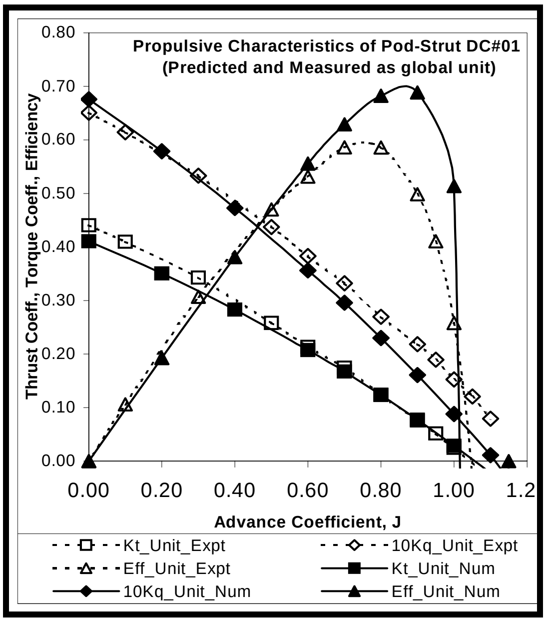

Fig. 9: Comparison of the measured (Expt.) and predicted (*PROPELLA*) propulsive characteristics of the whole unit (measured at global dynamometer) in Pod#01 in pull configuration.

4. Podded Propulsor Performance Predictions Using *PROPELLA*

4.1 Study of hub taper angle

As far as is known by the authors, there has not been any numerical or experimental work reported to date which studies the effects of root hub taper angle on propeller performance. The hydrodynamic part of the code was extended to include hub taper angle (-25° to 25°). The effects of hub taper angle on propulsive performance of the model propeller are evident when performance of the propellers with different taper angles is compared in terms of thrust coefficient, K_T, torque coefficient, K_Q and propeller efficiency, η, for a wide range of advance coefficient, *J*. *Fig.* 10 shows the predicted values of open water propulsive performance for hub taper angles of 15° push and –15° pull configurations. Propulsive performance for a straight hub propeller is included in the figure to emphasize how the hub taper angles influence propulsive performance (Islam *et al.* 2004).

The conclusions reached from the study are:

- The modified code was validated against measurements. The thrust coefficient, K_T and torque coefficient, K_Q values of the predictions and measurements for both propellers in pusher configurations were very close for a wide range of advance coefficients.
- Hub taper angle has more influence on thrust coefficient, K_T and torque coefficient, K_Q at highly loaded conditions than for lightly loaded conditions. For the same 15° hub taper angle, the pusher propellers produced less thrust for heavily loaded conditions, than the puller ones. The pusher propeller produced higher thrust and torque than the puller ones for lightly loaded conditions. These facts were observed both in predictions and measurements.
- Predicted pressure distributions on the blade root sections for puller propellers were found to be better than those of pusher propellers. Puller propellers should therefore produce more thrust than

a pusher propeller under the same operating condition. The study also showed that the hub taper angle changes the inflow conditions and the pressure distribution around the blade roots (r<0.20*R*) but for the rest of the blade sections the pressure distributions are almost identical.

4.2 Study of pod geometry and configurations

The hydrodynamic part of the code was extended to include pod-strut geometry (Islam 2004). In calculating the effect of the pod-strut body on propeller performance, the effect of proximity of the pod-strut body (blockage effect) was considered. In other words, the influence of the panels of the pod-strut bodies on the propeller body was considered in calculating the performance. The effect of skin friction of the pod-strut body on the performance of the whole unit (propeller with pod-strut) was obtained using a simple empirical formulation. Interaction effects between the propeller and pod-strut body, the propeller wake and other bodies and velocity induced by the pod-strut body and the propeller were all taken into consideration. An illustration of model propeller-pod-strut geometry is provided in *Fig.* 11.

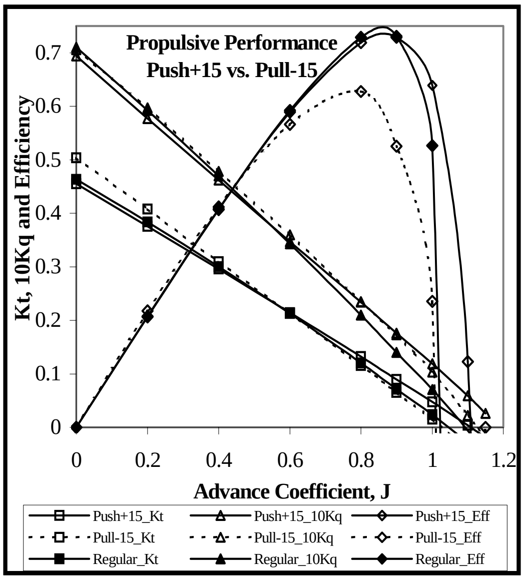

Fig. 10: Numerical results showing the effects of hub taper angle on the propulsive performance of propellers with hub taper angles of 0°, 15° and –15°.

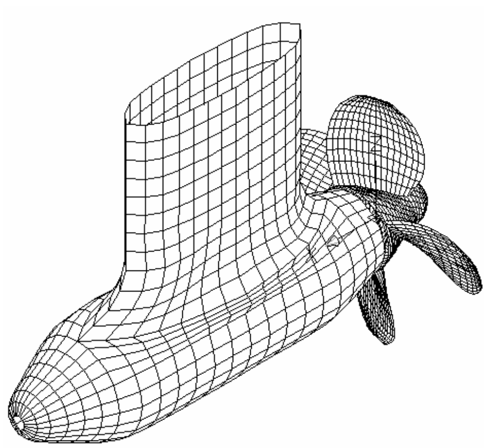

Fig. 11: Mesh view of the model propeller with pod-strut (Pod #01) geometry in puller configuration.

The 16 pods in the series and the pods attached to the propellers with appropriate hub angles are shown in *Fig.* 12. The two average pods were modeled to study the effects of pod-strut configurations (pusher and puller configurations) as well as azimuthing conditions (both static and dynamic) on the performance. The sixteen pods were modeled to study the pod-strut geometry effect on performance. A fractional factorial design of experiment (DOE) technique was used to combine five geometric parameters of the pod-strut-propeller and to obtain the pod series consisting of the 16 pods. The preliminary predicted performance coefficients of the 16 pods in the series are given in *Figs*. 13 and 14 in puller and pusher configurations, respectively. One example of the benefits of the numerical approach is that the effects of the strut distance can be evaluated more conveniently and affordably than through experiments. Different longitudinal positions of the strut can be investigated in a numerical experiment and the extremes can more easily be studied than with physical tests. The validation of the code in different configurations and in azimuthing conditions is currently being done.

The predicted values of the pods are being validated both for the pusher and puller configurations. The two average pods are being studied for static and dynamic azimuthing conditions.

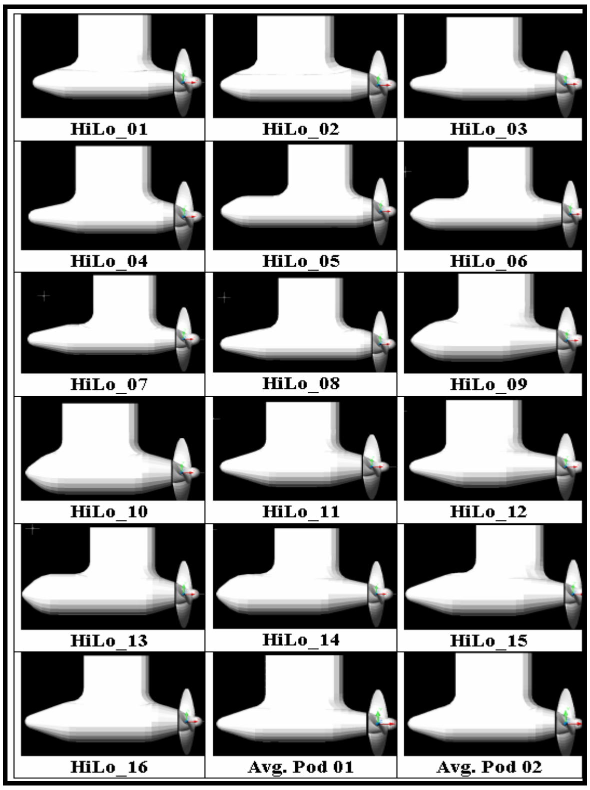

Fig. 12: Geometric models of the pod series and the average pods in pusher configurations used in the code.

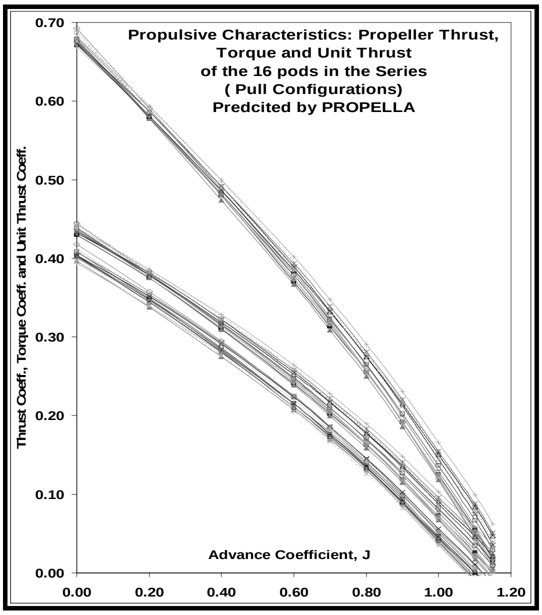

Fig. 13: Preliminary predicted performance coefficients of the 16 pods in the series in the puller configurations.

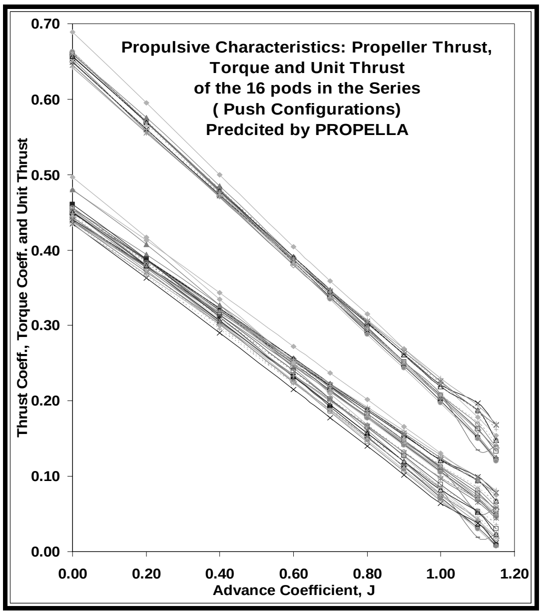

Fig. 14: Preliminary predicted performance coefficients of the 16 pods in the series in the pusher configurations.

4.3 Study of wake impingement

He *et al.* (2006) studied a wake impingement model (WIM) that has been incorporated into *PROPELLA* and applied in the simulation of a podded propeller wake impacting on a strut. Simulations for the hydrodynamic performance of the podded propeller were conducted, and the surface pressure on the strut was compared to a set of pressure measurements. As shown in *Fig.* 15, the wake of a blade is split when it passes the strut. *Fig.* 16 shows the simulated pressure distributions with/without WIM at an instance time step=144, 36 steps/revolution, blade phase angle = 0°. The conclusions reached from the study are summarized as follow:

Comparisons of the numerical results with corresponding experimental data indicate that the simulated pressure is in good agreement with experiments. Hence, it is concluded that the wake impingement model incorporated in the panel code can provide a convenient tool for the prediction of surface pressure fluctuation on a strut under a strong interaction with a propeller wake. However, the amplitude of the pressure fluctuation in the tip-vortex/strut interaction zone is under predicted; further refinement to the numerical method is necessary to improve this aspect of the model.

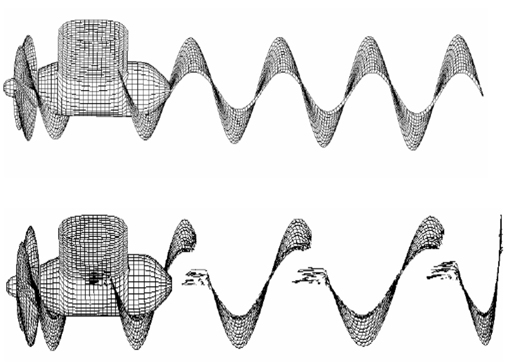

Fig. 15: Simulated Blade Wake after Passed the Pod and Strut; without WIM (upper) and with WIM (lower).

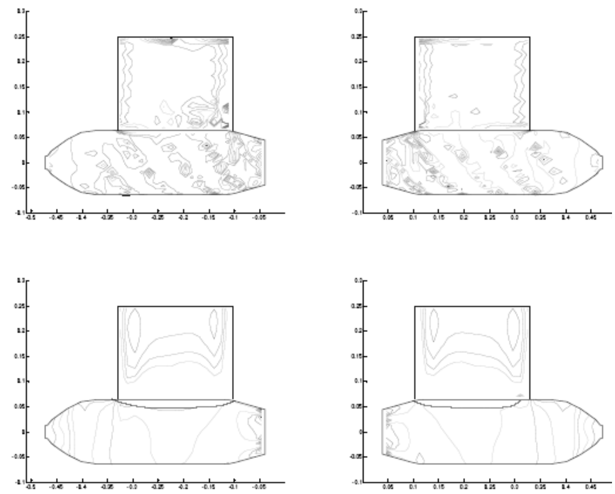

Fig. 16: Simulated Pressure Distributions with/without WIM at an Instance istep=144, 36 steps/revolution, blade phase angle = 0°; upper left – with WIM, star; upper right – with WIM, port; lower left – without WIM, star; lower right – without WIM, port.

4.4 Prediction of pod loads in Ice

Fluid-structure interaction between an ice sheet on the water surface and a podded R-Class propeller was examined and analyzed in terms of numerical simulation using an enhanced unsteady, multiple body panel method model (Liu *et al.* 2008). *Fig.* 17 shows the interaction scenario: the sawn ice is set to stand still in front of the podded R-Class propeller. As the diameter of the propeller is 300 mm, before the propeller approached the triangle region of the ice block, the distance from the tip of the propeller to the side edge of the ice was 350 mm, which is greater than the diameter of the propeller, so the blockage effect of the side edge of the ice was neglected. In numerical simulation, at a time equal to zero, the propeller was aligned with the base of the ice triangle. As the triangle was equilateral with an apex angle of 90°, the vertical distance was the half of the base. Therefore, the initial distance between the propeller plane to the tip of the triangle was 350 mm. The final time step when the zero proximity occurred was when the propeller plane passed the y-axis at which position the propeller plane and the ice edge formed an equilateral triangle with a base of 300 mm. *Fig.* 18 shows the meshed ice block, propeller, pod and strut in the flow domain.

The conclusion reached from the study can be summarized as:

- The new model was compared with the previous experimental data as well as the previous predictions by the same code using the integrated body model (all objects were assumed to be one piece).

- While the current model still needs further refinement, it produced reasonable results, for example the transient shaft loading, in terms of magnitude and direction, and hence it could be used for hydrodynamic prediction under proximity conditions, not only for ice but also for other interaction between propeller and other objects.

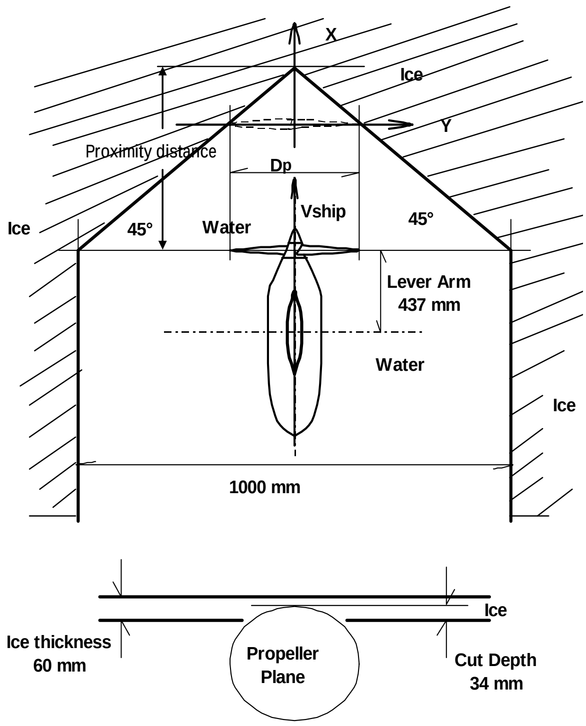

Fig. 17: Multi-body interaction in flow domain that consists of an ice block ahead of an r-class propeller, a pod and a strut.

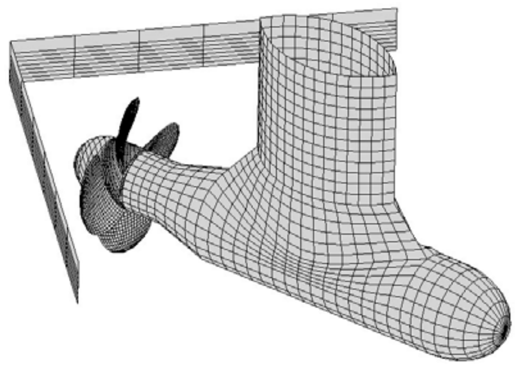

Fig. 18: The meshed ice block, propeller, pod and strut in the flow domain.

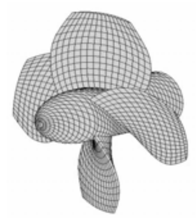

Fig. 19: Surface view of the optimized propeller.

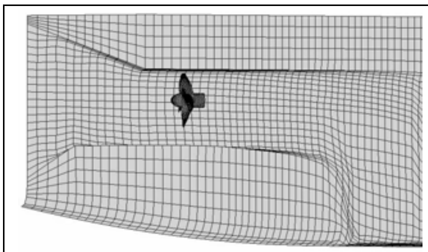

Fig. 20: Bottom view of the port propeller in the semi-tunnel under a rear part of the half hull.

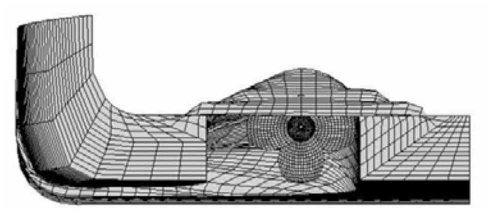

Fig. 21: Rear view of the port propeller in the semi-tunnel under a rear part of the half hull.

4.5 Design of special propeller

The code, *PROPELLA* was also used for a design and optimization procedure for a propeller installed on a twin-semi-tunnel-hull ship navigating in very shallow and icy water under heavy load conditions (Liu *et al.* 2006). The base propeller was first determined using classical design routines under open water condition utilizing existing model test data. In the optimization process, *PROPELLA* was used to vary the pitch values and distributions and take into account the inflow wake distribution, tunnel gap and cavitation effects.

Fig. 19 shows the mesh view generated and panelized by *PROPELLA* for computation. *Figs*. 20 and 21 are the bottom and rear view of the propeller-hull interaction mesh. The conclusions reached from the study are:

- The present approach is a combination of the base propeller determination using classical design method and the detailed optimization using hydrodynamic code.
- The methodology developed was then applied on a very shallow water semi-tunnel ship with two propellers navigating in an icy water environment.
- 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 inflow wake has a positive effect on the efficiency due 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 of a nozzle on a propeller.
- With the presence of the hull, the propeller thrust dropped but with a larger reduction in torque requirement. This in combination gave an increased efficiency.

5. Concluding Remarks

This paper describes the numerical aspects of a research program on podded propulsors, which is being undertaken jointly by the Ocean Engineering Research Centre at Memorial University of Newfoundland, the National Research Council’s Institute for Ocean Technology, Oceanic Consulting Corporation, and Thordon Bearings Ltd. Amongst the hydrodynamic issues that have been addressed through numerical predictions were questions regarding the effects of hub taper angle (propeller only case and pod-strut-propeller case), pod-strut configuration (push and pull), geometric variations, azimuthing conditions and pod-strut interactions (wake impingement effect) on podded propeller performance.

An existing panel method code, *PROPELLA* was extended to include hub taper angle and the propulsive performance of four model propellers were calculated and validated against corresponding experimental results. Two model pod-strut bodies were modeled and integrated into the code to study the effects of pod-strut body on propulsive performance of a propeller with taper angles of 15° and 20° both in pusher and puller configurations. Significant effects of the presence of pod-strut body were found in the predictions especially in pusher configurations. Another sixteen pod-strut bodies were modeled to study the effect of geometric variations on propulsive performance. Calculation was made both in pusher and puller configurations for the pods and reasonable agreement were achieved between the predictions and measurements. The code is being modified to study the podded propulsors’ performance at static and dynamic azimuthing conditions. Validation of this study is currently being done.

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