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

Islam M[1], Liu P[2] and Veitch B[1]

[1]Faculty of Engineering and Applied Science, Memorial University of Newfoundland, Canada
[2]Institute for Ocean Technology, National Research Council Canada, 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 the 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 "propeller only case" and "pod unit case" and 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's performance at static and dynamic azimuthing conditions. Validation of this study is currently being done. The code is also capable of performing simulations with propeller and any arbitrary bodies like ship hull, underwater vehicles with fins.

Keywords: Podded Propulsors, Pusher and Puller Propellers, Propulsive Performance, Hub Taper Angle, Azimuthing Conditions, Wake Impingement Effect.

1. INTRODUCTION

The podded propulsion system is a modern ship propulsion concept. Figure 1 shows a schematic view of the major components of a typical podded propulsion system. The idea of placing an electric engine inside the pod shell solved the problem of delivered power, making the new system attractive for big cruise ships, large tankers, ice breakers and ferries with diesel electric propulsion. The pod propulsion systems have proven to be a very attractive alternative propulsion system for ship owners (especially for large commercial vessels). The reasons for this may be due to the facts that this propulsion system offers enhanced hydrodynamic efficiency and improved manoeuvring performance.

Basically, two types of pod propulsion systems are used in the marine industry, namely, pusher pod propulsion system and puller pod propulsion system. In a pusher pod propulsion 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.

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,

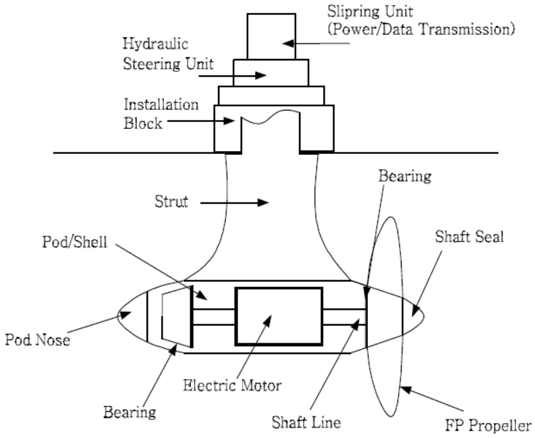

Fig 1: A schematic diagram of podded propulsors showing all major components of this system.

such as panel methods and viscous flow method. The numerical methods used to model and predict the performance is primarily the panel method.

A research program titled "Systematic Investigation of Azimuthing Podded Propeller Performance" on podded propellers has been undertaken jointly by the Ocean Engineering Research Centre (OERC) at Memorial University of Newfoundland (MUN), the National Research Council's Institute for Ocean Technology (IOT), Oceanic Consulting Corporation, and Thordon Bearings Ltd. The program combines parallel developments in numerical prediction methods and experimental evaluation. The work addressed 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 source and doublets are uniformly distributed over flat quadrilateral panels used to discretize simpler propeller geometry. Similar singularities 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 [1]. The structure, functionalities, implementation and demonstration of the code, *PROPELLA*, are discussed in detail in [2]. 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 forces include:

(1) Instantaneous and mean pressure distribution on the blade, nozzle, and rudder surfaces;

(2) Instantaneous and mean shaft thrust and torque, which are essential for marine propeller design;

(3) Blade in-plane, out-of-plane bending moments and blade spindle torque; and

(4) Shaft transversal forces such as vertical, horizontal forces and their resultant.

2.2 Structure of *PROPELLA*

PROPELLA consists of four major components. They are:

(1) Geometry and motion parameter input file generator INPUT, a ASCII text file;

(2) Propeller surface mesh generator;

(3) Pre- and post-processor and

(4) 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:

(1) An advanced iterative, dense, asymmetrical matrix solver, the Bi-Conjugate Gradient Stability (BiCGSTAB) method;

(2) A numerical iterative pressure Kutta (IPK) condition procedure formulated by a modified Newton-Raphson non-linear iteration scheme, the Broyden iteration;

(3) A low order quadrilateral/triangle kernel to obtain the influence coefficients;

(4) An optional hyperboloidal kernel to find the influence coefficients for the twisted panels that appear in the tip region of the blade; and

(5) A semi-empirical scheme that models chop-off and fill-in pressure for K_T and K_Q of a propeller under cavitation.

(6) A vortex-wake roll-up model with iteration was also built in to the code

(7) Force and torque prediction modules to predict 6-degree-freedom forces/torque at any panel centroid for forces and any described line for torques on the propeller surface.

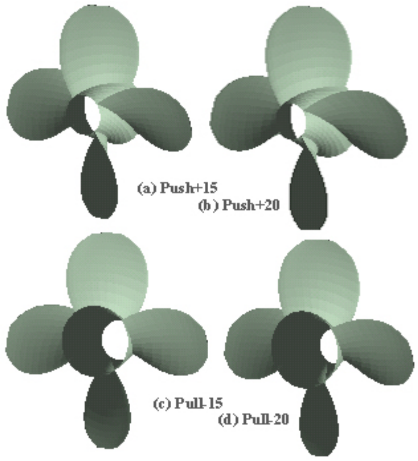

Fig 2: Four model propellers (rendered model generated by PROPELLA). Figure (a), (b), (c), (d) are the propellers with hub taper angles of +15° (push), +20° (push), -15° (pull), -20° (pull), respectively.

3. VALIDATION OF THE CODE: *PROPELLA*

The code, *PROPELLA* has been validated for more than a dozen propellers in terms of hydrodynamic properties since its development about a decade ago [3]. 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 figure 2). Figures 3 and 4 show comparisons of propeller open water performance between measurements and predictions for model propellers, Push+15 and Pull-15, respectively [4,5 and 6].

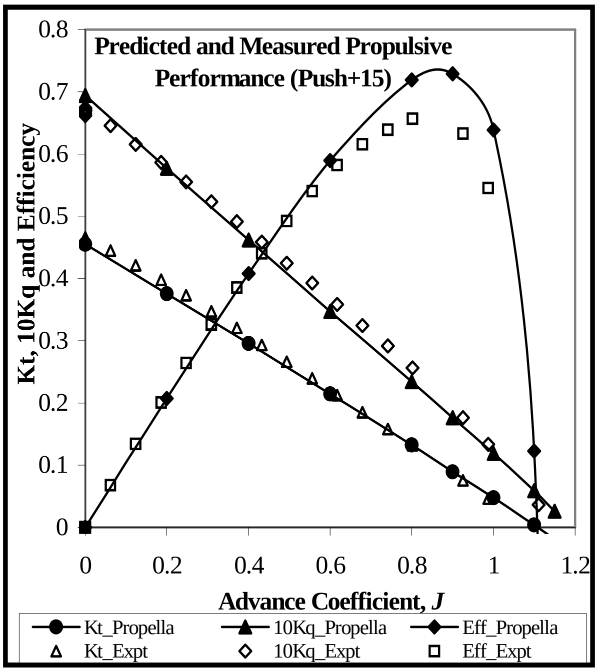

Fig 3: Comparison of the measured (Expt) and predicted (*PROPELLA*) propulsive characteristics of the model propeller, Push+15, with hub taper angle of 15° (push configuration).

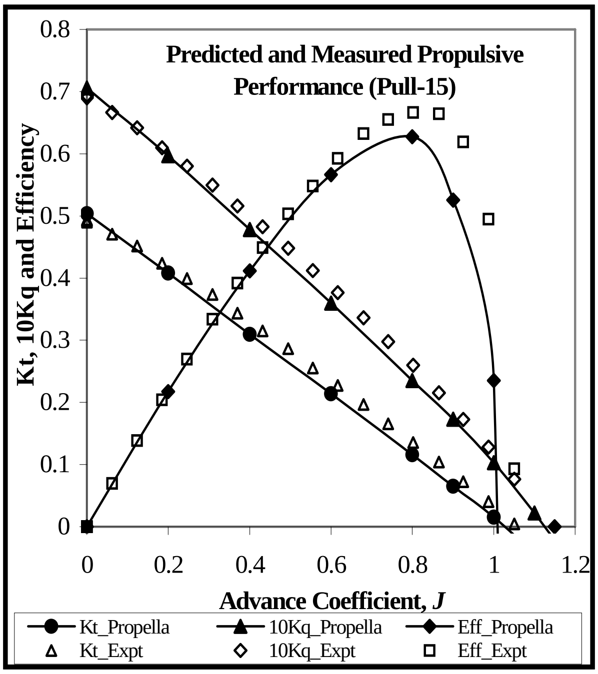

Fig 4: Comparison of the measured (Expt) and predicted (*PROPELLA*) propulsive characteristics of the model propeller, Pull-15, with hub taper angle of -15° (pull configuration).

In a recent study the code was further validated for two propellers with two different pod-strut combinations taken out from a series of 16 pods [7]. The validation consists of comparison of performance of the propeller measured at the propeller hub and of the unit measured as a whole. Figures 5 and 6 show comparisons of propeller open water performance between measurements and predictions for the propeller-pod-strut systems Pod #01.

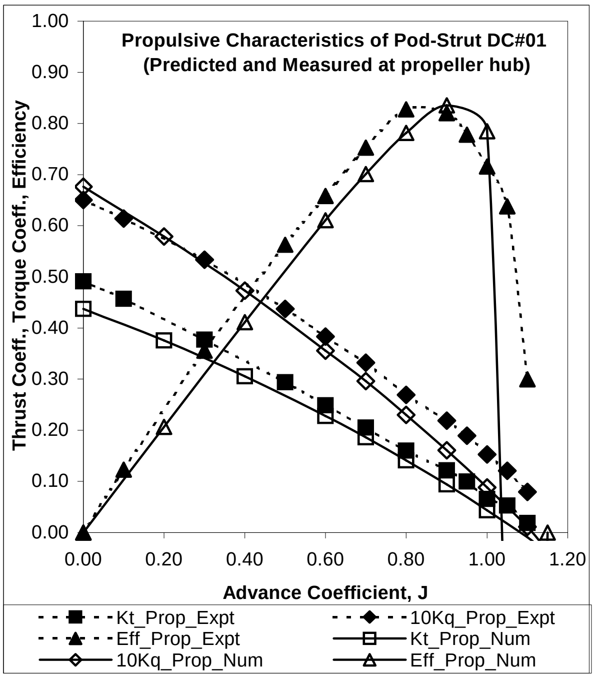

Fig 5: Comparison of the measured (Expt) and predicted (*Propella*) propulsive characteristics of the propeller (measured at propeller shaft dyno) in Pod#01 in pull configuration.

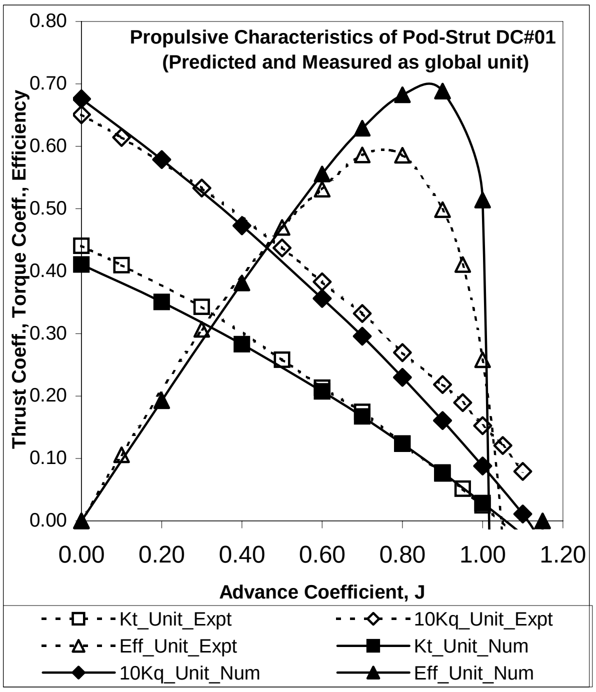

Fig 6: Comparison of the measured (Expt) and predicted (*Propella*) propulsive characteristics of the whole unit (measured at global dyno) in Pod#01 in pull configuration.

4. PODDED PROPULSOR PERFORMACNE PREDICTIONS USING PROPELLA

4.1 Study of Hub Taper Angle

The hydrodynamic part of the code, *PROPELLA* 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 K_T, K_Q and η, for a wide range of J. Figure 7 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 [5].

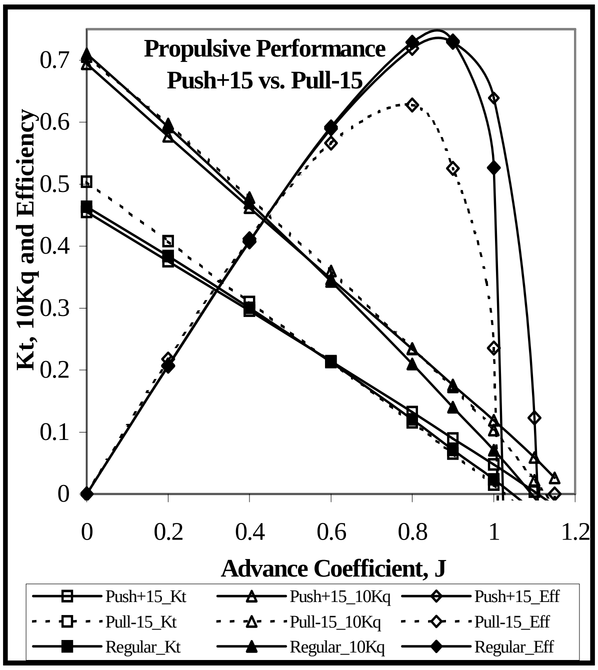

Fig 7: Numerical results showing the effects of hub taper angle on the propulsive performance of propellers with hub taper angles of 0°, 15° and –15°.

The conclusions reached from the study are:

(1) The modified code was validated against measurements. The K_T and K_Q values of the predictions and measurements for both propellers in pusher configurations were very close for a wide range of advance coefficients

(2) Hub taper angle has more influence on K_T and 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.

(3) Predicted pressure distributions on the blade root sections for puller propellers were found to be more desirable 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 Configuration

The hydrodynamic part of the code, *PROPELLA* was extended to include pod-strut geometry [4]. 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 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 was all taken into consideration. An illustration of model propeller-pod-strut geometry is provided in figure 8.

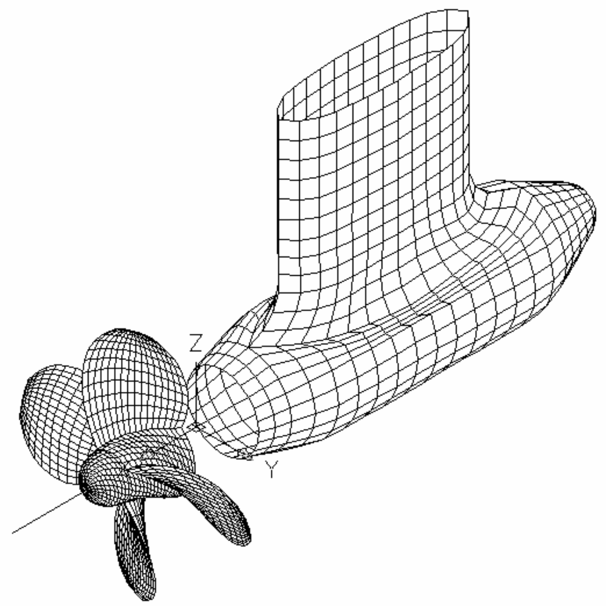

Fig 8: Mesh view of the model propeller with pod-strut geometry in pusher configuration.

The 16 pods in the series and the average pods attached to the propellers with appropriate hub angles are shown in figure 9. 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. One example of the benefits of the numerical approach is that the effects of the strut distance can be evaluated more conveniently and affordably using numerical methods. 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 are currently being done.

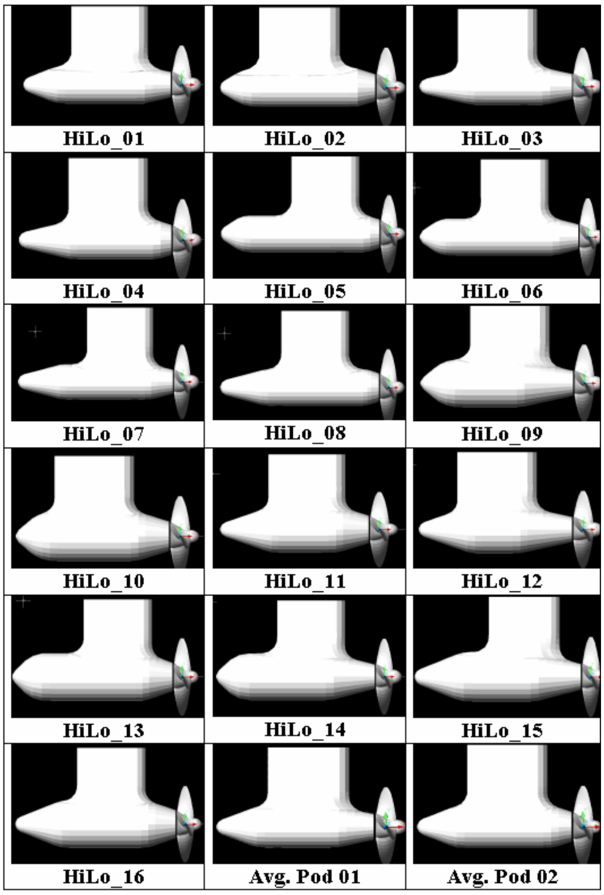

Fig 9: Geometric models of the pod series and the average pods in pusher configurations to be used in the code.

4.3 Study of Wake Impingement

He [8] studied a wake impingement model (WIM) that has been incorporated into a panel method code, *PROPELLA,* and applied in the simulation of a podded propeller wake impacting on a strut. Simulations for the hydrodynamic performance of the podded propeller are conducted, and the surface pressure on the strut is compared with a set of pressure measurements. As shown in figure 10, the wake of a blade is split when it passes the strut. The conclusions reached from the study are summarized as follow:

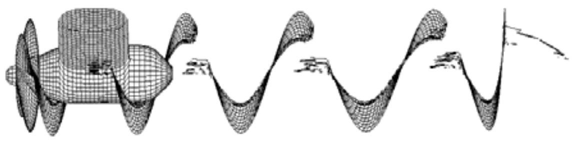

Fig 10: Simulated Blade Wake after Passed the Pod and Strut.

Comparisons of the numerical results with corresponding experimental data indicate that the simulated pressure is in a 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.

4.4 Predictions 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 a newly enhanced unsteady, multiple body panel method model [9]. Figure 11 shows the interaction scenario: the sawn ice is set to stand still in front of the podded R-Class propeller. The conclusion reached from the study can be summarized as:

(1) 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).

(2) While the current model still needs further refinement, it produced relatively 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 condition, not only for ice but also for other interaction between propeller and other objects.

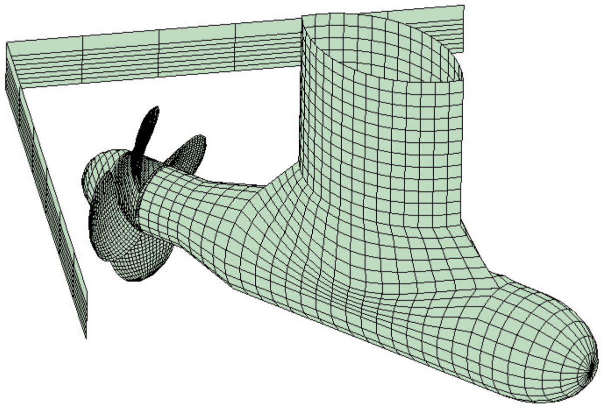

Fig 11: Multi-body interaction in flow domain that consists of an ice block ahead of an r-class propeller, a pod and a strut.

4.5 Design of Special Propeller

The code, *PROPELLA* was also used to 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 [10]. 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.

Figure 12 shows the mesh view generated and panelized by *PROPELLA* for computation. Figure 13 and 14 are the bottom and rear view of the propeller-hull interaction mesh. The conclusions reached from the study are:

(1) The present approach is a combination of the base propeller determination using classical design method and the detailed optimization using hydrodynamic code.

(2) The methodology developed was then applied on a very shallow water semi-tunnel ship with two propellers navigating in an icy water environment.

(3) 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.

(4) 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.

(5) 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.

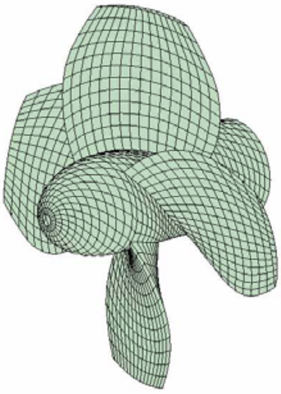

Fig 12: Surface view of the optimized propeller.

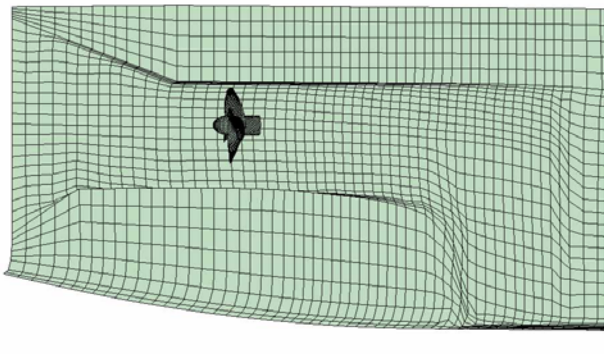

Fig 13: Bottom view of the port propeller in the semi-tunnel under a rear part of the half hull.

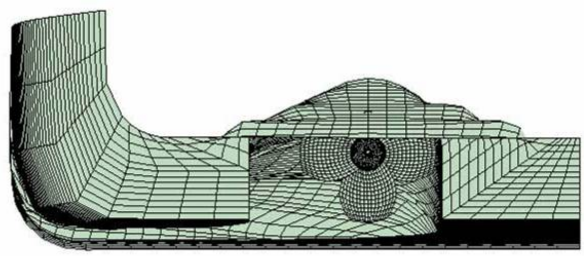

Fig 14: Rear view of the port propeller in the semi-tunnel under a rear part of the half hull.

4.5 Other Applications of *PROPELLA*

The recent extension of the code enables simulation of podded propulsion system both in pusher and puller configurations with arbitrary pod-strut bodies and also simulation of an environment consisting of any arbitrary lifting and not-lifting bodies with propeller. For example, the extended code was used for modeling and performance evaluation of an autonomous underwater vehicle (C-SCOUT) and a standard (DREA) submarine (see figure 15). Validation of the predicted performance characteristics is currently being done.

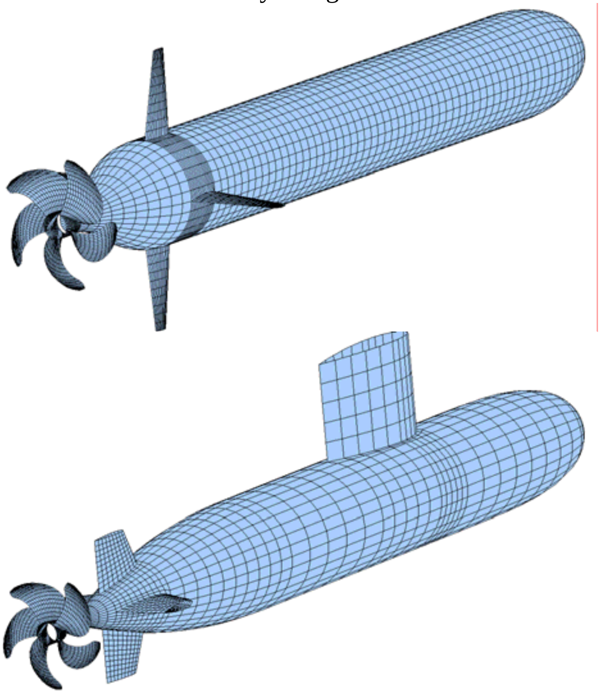

Fig 15: An underwater vehicle and a standard submarine with propellers (modeled using *PROPELLA*).

4. 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 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 effect of the presence of pod-strut body was 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 usher 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's performance at static and dynamic azimuthing conditions. Validation of this study is currently being done. The code is also capable of performing simulations with propeller and any arbitrary bodies like ship hull, underwater vehicles with fins.

5. ACKNOWLEDGEMENT

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7. NOMENCLATURE

Symbol	Meaning	Unit
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)
Q	Propeller torque	(Nm)
T_{Prop}	Propeller thrust	(N)
T_{Unit}	Unit thrust	(N)
$K_{T\text{Unit}}/K_{T\text{x}}$	Unit thrust coefficient, $T_{\text{Unit}} / \rho n^2 D^4$	
$K_{T\text{Prop}}$	Propeller thrust coefficient, $T_{\text{Prop}} / \rho n^2 D^4$	
$10K_Q$	Propeller torque coefficient, $10Q / \rho n^2 D^5$	
J	Propeller advance coefficient, V_A / nD	
η_{Unit}	Unit efficiency, $J / 2\pi \times \left(K_{T\text{Unit}} / K_Q\right)$	