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A BRIEF OVERVIEW OF RESEARCH ACTIVITIES ON PODDED PROPULSORS IN MEMORIAL UNIVERSITY OF NEWFOUNDLAND
PART A: EXPERIMENTAL ACTIVITIES

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ABSTRACT

This paper describes a research program on podded propulsors that combines parallel developments in numerical prediction methods and experimental evaluation. Amongst the hydrodynamic issues that have been identified are questions regarding the effects of hub taper angle (propeller only case and pod-strut-propeller case), pod-strut configuration (push and pull), azimuthing conditions, pod-strut interactions (wake impingement effect), gap pressure, and pod-strut geometry (design of experiments method) on podded propulsor's performance. In the experimental side, a pod dynamometer system, which consisted of a six-component global dynamometer and a three-component pod dynamometer were designed manufactured and used to perform measurements on propeller thrust and torque, unit forces and moments in the three orthogonal directions in pusher and puller configurations. Four propellers with same blade section but different hub taper angles were design and used to fit with eighteen pod-strut shells. Among the pods, two pod-strut models were based on the average dimensions of commercial pods and used to study the hub angle and azimuthing conditions effect on propulsive performance. The rest sixteen pods were designed and manufactured to study the effect of geometric parameters on hydrodynamic performance using a design of experiments technique. In another study, an experimental method was implemented in a cavitation tunnel to evaluate the wake/strut interaction of a podded propeller model. All of the measurements showed consistency and supported general hydrodynamic principles.

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

1. INTRODUCTION

A podded propulsion system consists of a fixed pitch propeller driven by an electric motor through a short shaft. The shaft and motor are located inside a pod shell. The pod unit is connected to the ship's hull through a strut and slewing bearing assembly. This assembly allows the entire pod unit to rotate and thus the thrust developed by the propeller can be directed anywhere in the horizon in a 360° compass. The podded propeller arrangement eliminates the requirement for a rudder and additional appendages such as shaft brackets. This arrangement results in lower appendage drag hence lower power consumption. The shorter shaft can also help reduce noise and vibration. The propeller works in more uniform flow, which reduces load variations and risk of cavitation. Podded propulsion systems also yield much better maneuverability than conventional screw propellers, especially in confined water operation. Despite these advantages, podded propulsion systems have some disadvantages, such as high capital cost, bearing failure and some other structure problems confronted while operating in oblique flow conditions. Fig. 1 shows a comparison of arrangements of a conventional propeller-rudder propulsion system and a puller podded propulsion system.

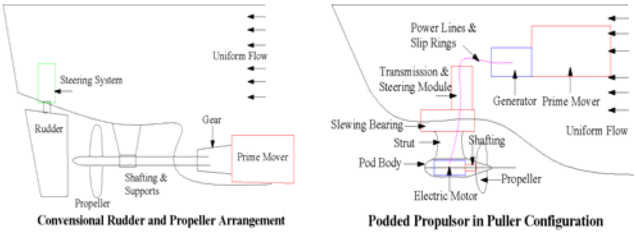

Fig 1: Conventional propulsion system vs. podded propulsion system

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. Some of the short term objectives of the project are outlined as follows:

(1) Quantify systematically the effects of podded propulsor configuration variations on propulsion performance.

(2) Develop computational methods for podded propeller performance prediction.

(3) Develop an extrapolation method for powering prediction of ships fitted with podded drives.

(4) Develop new instrumentation for performance evaluation of podded propellers at model scale.

(5) Develop specialty manufacturing capability in Canada for high quality, affordable model propellers.

Amongst the hydrodynamic issues that have been identified and being addressed are questions regarding the effects of hub taper angle ([1] to [7]), pod-strut configuration ([1] and [7]), pod-strut interactions [8, 9]), gap pressure [10], pod-strut geometry ([11] to [13]), pod gap effect [14] and static azimuthing conditions [15] on podded propulsor performance. This paper presents a technical overview of the experimental investigations being done to study various hydrodynamic aspects of podded propulsors in open water conditions.

2. EXPERIMENTAL APPARATUS AND APPROACH

A custom-designed dynamometer system [10] was designed and used for the measurements. In the instrumentation, a motor fitted above the propeller boat (wave shroud) drives the propeller via a belt system. The propeller shaft is 1.5D (Propeller diameter) below the surface. The part of the shaft above the strut goes through the shroud. The wave shroud stays 5 to 10 mm above the water surface to suppress waves caused by the strut piercing the surface. A dynamometer with the ability to measure propeller and pod forces and moments was used to measure the following items:

(1) Propeller thrust (T_{Prop}) and torque (Q_P)
(2) Unit longitudinal force (F_X) and moment (M_X)
(3) Unit transverse force (F_Y) and moment (M_Y)
(4) Unit vertical force (F_Z) and moment (M_Z)

Also the water temperature, carriage speed, V_A and the rotational speed of the propeller, n, were measured. The dynamometer system has two major parts. The first part is the pod dynamometers, which will measure the torque of the propeller at the propeller shaft. The propeller thrust will be measured in two different locations. The first location for the thrust measurement is inside the hub of the propeller and the second location is on the propeller shaft at the end the pod opposite to the propeller. The second part of the system is the global dynamometer, which will measure the unit thrust at the location above the wave shroud. The carriage speed and rotational speed of the propeller were recorded in the standard manner. The pod dynamometer system is depicted in figure 2. It has a lift system drive train (not shown in the figure), which consists of the electric drive motor, timing pulleys and drive belts to operate lead screws. Each lead screw has a timing pulley to allow for synchronous operation of all four screws to raise or lower the pod unit. The fixed frame rests on the towing carriage rails and provides stability for the rest of the instrumentation package. The live frame houses the global dynamometer instrumentation package. It is mounted on four lead screws that allow the entire pod unit to be raised out of the water. This frame moves with the pod unit during lifting and is secured to the fixed frame during testing. The main drive train consists of a 9.065 KW (kilo Watt) electric motor coupled to a 90° gearbox. This gearbox is connected to the main pulley, which drives the belt that rotates the propeller shaft. The instrumented pod unit houses the propeller and pod geometry. Figure 3 shows the dynamometer and the lifting system installed on the towing tank rails.

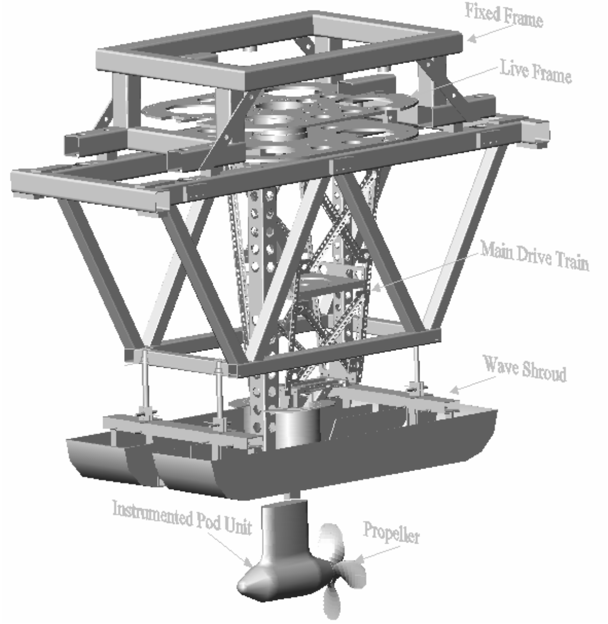

Fig 2: Pod dynamometer system components [10].

Fig 3: Pod dynamometer system installed on the OERC towing tank rails.

Four propellers with same blade section but different hub taper angles (details of the propeller geometry can be found in [16]) were design and used to fit with eighteen pod-strut shells in pusher and puller configurations. Among the pods, two pod-strut models were based on the average dimensions of commercial pods and used to study the hub angle effect on propulsive performance. The rest sixteen pods were designed and manufactured to study the effect of geometric parameters [11-13] on hydrodynamic performance using a design of experiments technique [17]. The two average pods were also used to study the hydrodynamic performance variations with the change of advance coefficients and static azimuthing conditions [15]. In another study, an experimental method was implemented in a cavitation tunnel to evaluate the wake/strut interaction of a podded propeller model [8,9]. The study includes surface pressure measurements on the strut around the leading edge, and visual investigations of cavitation tip vortices. The first average pod was used for this study. The pressure measurements at 56 different locations were realized by eight repeated tests with seven pressure transducers. The transducers were relocated before each repeated test. Each test consisted of five flow speeds, which varied the advance coefficient.

3. MEASUREMENTS AND RESULTS

The experimental study of podded propulsors was categorized into two major groups: propeller only case (baseline propellers) and propeller with pod body (pod unit) case. The study of "propeller only case" essentially consisted of the study of hub taper angle [1] of podded propellers in open water and cavitating conditions. The study of "pod unit" consisted of the study of hub angle, pod geometry, pod gap, static azimuthing conditions and wake/strut interactions of the pod unit in pusher and puller configurations. A brief overview of the studies is outlined in the following sections.

3.1 Propeller Only Cases

In this part of the research work, the effect of hub angle on the performance of podded propeller in opens and cavitating conditions were studied [1-7]. The definition of hub angle and propeller configurations are shown in figure 4.

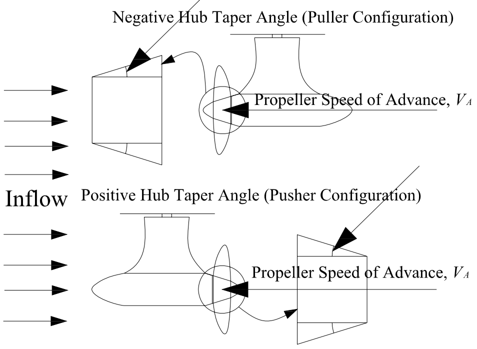

Fig 4: Podded propulsion system: puller and pusher types and the definition of hub taper angle.

3.1.1 Hub angle effect in opens conditions

Taylor [6,7] studied the effect of hub taper angle on the performance of podded propeller (propeller without pod-strut body) in opens condition. Figure 5 shows some of the results obtained from the investigation. The conclusions derived from the study are:

(1) Pull propellers has higher bollard thrust and torque coefficients than the push ones as well as higher maximum efficiency.

(2) Increasing the hub taper angle increased the thrust and torque coefficient at bollard conditions but tends to decrease the maximum efficiency.

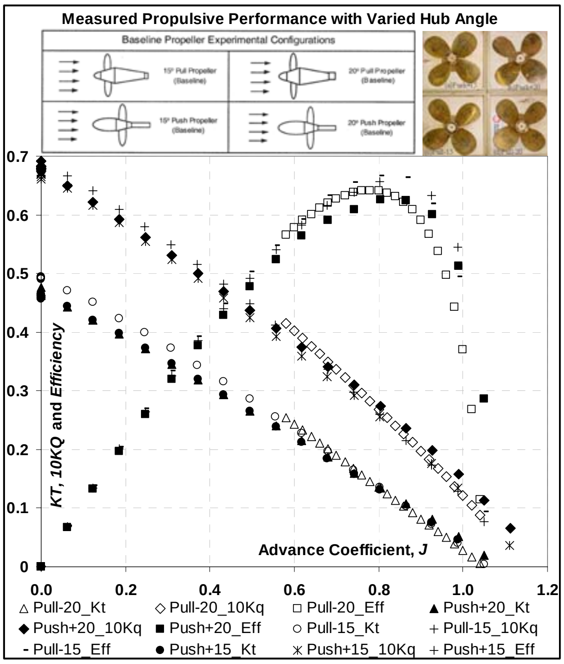

Fig 5. Performance characteristics of podded propeller (propeller only case) with four different hub taper angles.

3.1.2Hub angle effect in cavitating conditions

Islam [3, 5] studied the effect of hub taper angle on the performance of podded propeller in various cavitating conditions. Figure 6 shows a comparison of propeller thrust coefficient of two propellers with opposite hub taper angles. The conclusions derived from the study are:

(1) All of the four propellers showed similar cavitation and inception patterns at the same operating conditions.

(2) For both pusher and puller propellers, increasing hub taper angle decreased the efficiency at all cavitating conditions.

(3) At all cavitation numbers, the puller propellers produced more thrust and torque than the pusher propellers at lower advance coefficient.

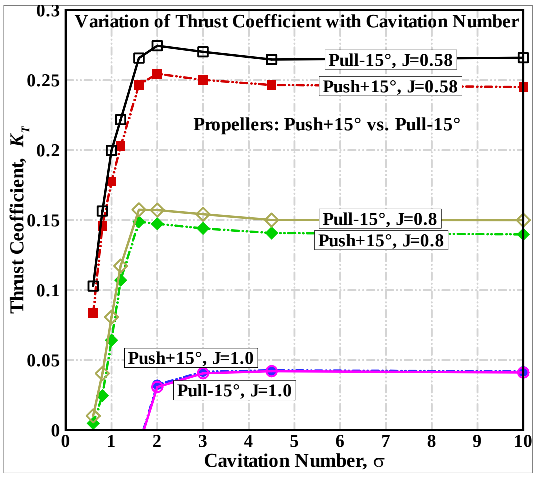

Fig 6: Comparison of thrust coefficient (Push+15° and Pull-15° propellers) variation with cavitation number for fixed advance coefficients.

3.2 Propeller with Pod Body (Unit) Cases

The study of pod unit (propeller attached to pod-strut body) was carried out in two groups: study in straight-ahead conditions and study in azimuthing conditions. The pod unit were tested in both pusher and puller configurations.

3.2.1 Study of Hub angle and Configurations in Straight-Ahead Condition

Taylor [7] and Islam [18] studied the effect of hub taper angle on the performance of podded unit in opens condition. Figure 7 shows a comparison of unit performance coefficients of two average pods in puller configurations. The conclusions derived from the studies are:

(1) Puller pod unit outperformed the pusher unit in all advance coefficients in straight ahead conditions.

(2) Increasing the hub taper angle increased the thrust and torque coefficient at low advance coefficient values, both for puller and pusher units.

(3) Increasing the hub taper angle tends to decrease the maximum efficiency.

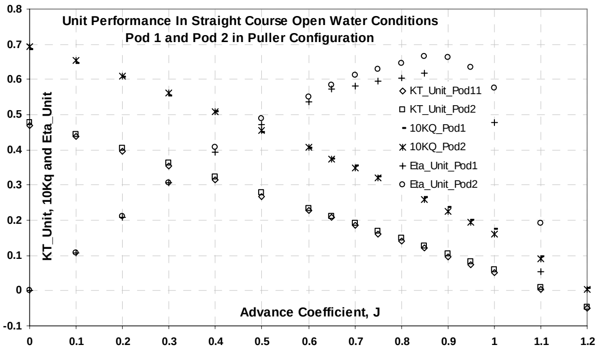

Fig 7: Propulsive performance for the pod units (pod-strut-propeller): Avg. pod 1 and Avg. pod 2.

3.2.2 Study of Pod-Strut-Propeller Geometry

A series of 16 pods were designed using a fractional factorial design technique to study the effects of five geometric parameters (pod diameter, pod length, pod taper length, strut distance and propeller hub angle) of podded propulsors in pusher and puller configurations [11-13]. The definition of the geometric parameters is shown in figure 8. Figure 9 shows sixteen pod models used with the four propeller models (see figure 4) to study the geometric parameters using a design of experiment technique. Figure 10 shows the variation of propeller efficiency with the varied geometry of the pod models. The conclusion derived from the study can be summarized as follows:

(1) Pod diameter, hub angle, strut distance had significant effect on propulsive performance of both puller and pusher propulsors but with different magnitude and nature.

(2) Taper length of the pod aft end, the end away from the propeller, did not have a significant influence on performance of the puller propulsors within the range tested. However, it had significant effect on unit thrust of the pusher propulsors at all advance coefficients.

(3) The interaction of the factors pod diameter and hub angle had significant effect on both propeller and unit thrust and torque coefficients at moderate advance coefficient for the puller propulsors

(4) For the pusher propulsors, the interaction of the factors pod length and pod taper length had noticeable effect on propeller thrust for low advance coefficients.

(5) For the pusher propulsors, the interaction effect of pod diameter and pod length was significant on unit thrust coefficient at low advance coefficients.

(6) The measurement showed that there were significant variations in the propeller thrust, torque, unit thrust and propeller and unit efficiencies values due to the variations of the geometric parameters of the pods.

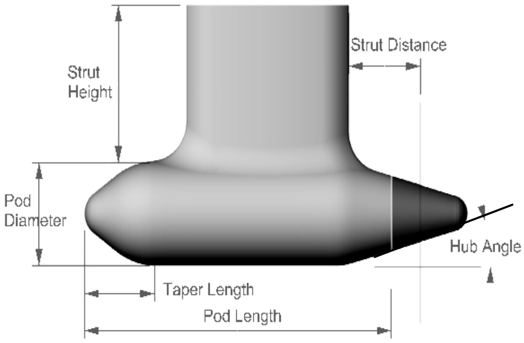

Fig 8: Definition of the geometric parameters.

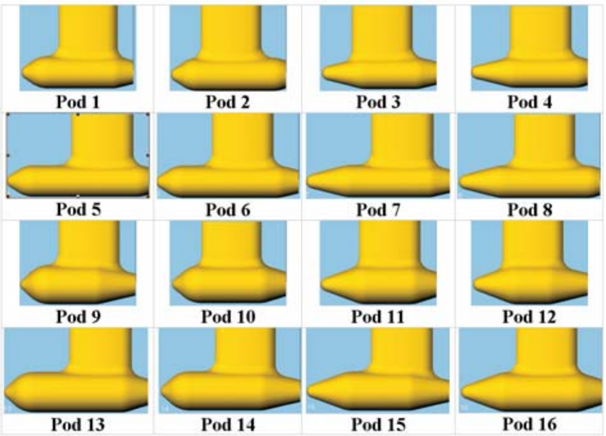

Fig 9: Sixteen pod models.

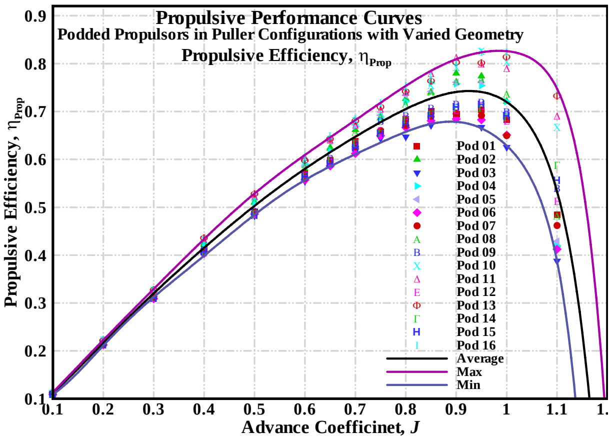

Fig 10: Propulsive efficiency of the propeller of the sixteen model pods in puller configurations.

3.2.3 Study at Static Azimuthing conditions

Islam [15, 18] investigated the effects of azimuthing conditions on the propulsive performance of podded propulsors in puller and pusher configurations. A model pod fitted with two propellers (for the two configurations) was tested using the custom designed pod testing system [10]. The unit was tested to measure the forces on the whole unit in the three co-ordinate directions as well as thrust and torque of the propeller for a range of advance coefficients combined with the range of static azimuthing angles from +30° to –30° with 5° and 10° increments. The variations in propulsive performance of the unit with change of azimuthing angle and advance speed in the two configurations were examined. Figure 11 shows the unit thrust coefficient of the pod in eleven different azimuthing conditions in puller configurations. Figure 12 shows the unit efficiency of the pod unit in pusher configurations in similar azimuthing conditions.

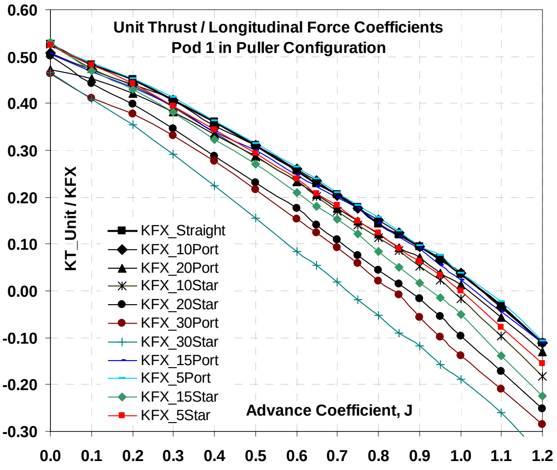

Fig 11: Unit thrust coefficient plots for Pod 1 at different azimuth conditions.

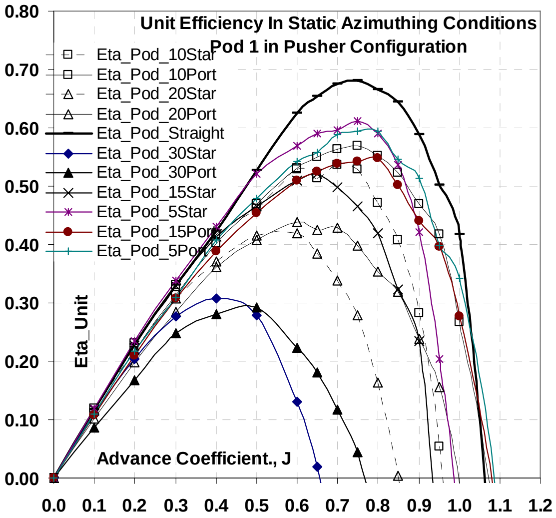

Figure 12: Unit efficiency plots for Pod 1 at different azimuth conditions.

The following conclusions were reached from the study.

(1) The unit force and moment coefficients of the propulsors showed a strong dependence on the propeller advance coefficient, azimuth angle and directions.

(2) In puller configurations, the maximum unit efficiency was found at 5° portside azimuthing conditions whereas in pusher configuration, the maximum unit efficiency was found in straight course operating conditions.

(3) Both in puller and pusher configurations, the propulsor with positive azimuth angles showed an increasing transverse force with the increase of *J* and the propulsor with negative azimuth angles showed a decreasing transverse force with the increase of *J*.

(4) For pusher configurations, the nature of the steering moment coefficient curves was completely different from those in the puller configurations.

3.2.4 Study of Pod Gap Distance

Islam [14] presented preliminary results of an experimental study on the effect of gap distance on propulsive characteristics of puller podded propulsors in straight course and static azimuthing open water conditions. The gap distance is the axial distance between the rotating (propeller) and stationary (pod) part of a podded propulsor (see figure 13). The experiments consisted of testing of a model pod unit in puller configuration at gap distances of 0.3%, 1.0% and 2.0% of propeller diameter, at straight-ahead and 10°Port, 20°Port, -10°Starboard and –20°Starboard azimuthing conditions for the advance coefficient values of 0.0 (bollard pull condition) to 1.2. Figure 14 shows the propulsive performance of the pod unit at three different pod gap distances in puller configurations.

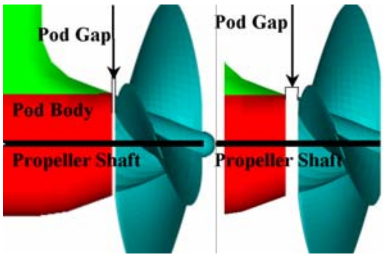

Fig 13: Definition of pod gap distance.

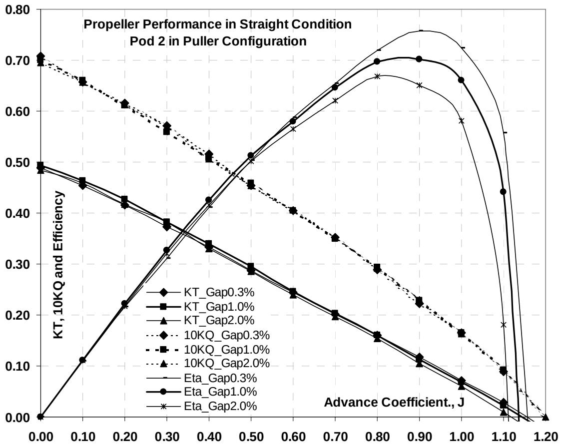

Fig 14: Propeller performance coefficients of Pod 2 in straight ahead condition.

The following conclusions were reached from the study:

(1) Gap distance did not affect the propeller torque for any of the advance coefficient values in straight-ahead condition. However, the thrust and hence the propulsive efficiency were affected by the change in pod gap distance and the effect was increased with the increase of advance coefficients. At azimuthing conditions, both the propeller thrust and torque coefficients were affected by gap distance.

(2) The unit thrust and efficiency were not affected by the change in gap distance for any values of advance coefficients in any of the azimuthing conditions. It was also concluded that unit side and vertical force coefficients and unit axial and steering moments were not affected by the change in gap distance both in straight-ahead and azimuthing conditions for any of the advance coefficient values.

3.2.5 Study of Wake Impingement Effcets

He [9] performed an experimental study in a cavitation tunnel on the wake/strut interaction of a podded propeller model. The study included surface pressure measurements on the strut around the leading edge, and visual investigations of cavitation tip vortices. The region of pressure measurements on the strut ranges from 0.6 to 1.2 of the propeller radius, *R*, and from the leading edge downstream to 0.4 of the chord length on both sides of the strut. Within this region, the pressure measurements at 56 different locations were realized by eight repeated tests with seven pressure transducers. A cycle of the tip vortex/strut interaction is demonstrated by a set of pictures in Figure 15.

The conclusion derived from the study can be summarized as follows:

(1) st pressure was found to occur on the stretched side near the leading edge near the intersection of the pod and the strut.

(2) est amplitude of pressure variation was found on the leading edge of the strut around = 1.0*R*, for all tested advance coefficients.

(3) In cases of low advance coefficients, the pressure at some of measurement points on the compressed side demonstrated a double-trough shape within a single period of the vortex filament impacting process.

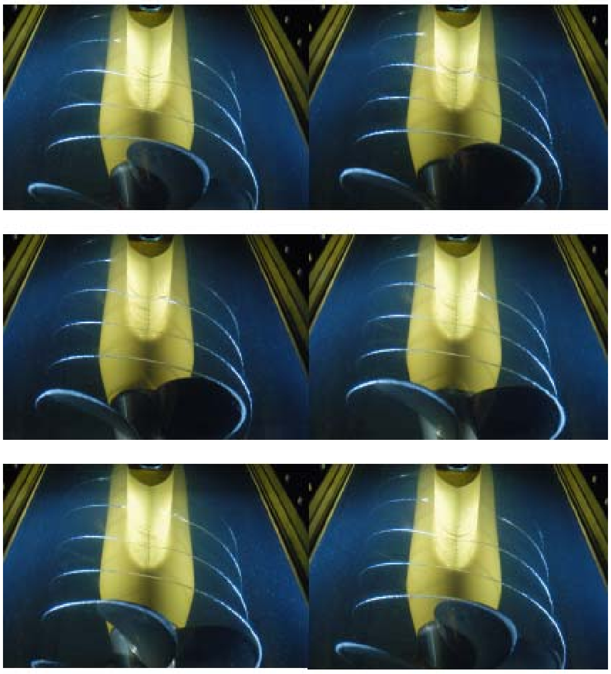

Fig 15: A Cycle of Tip Vortex/Strut Interaction
row 1 left, approach; row 1 right, touched;
row 2 left, bended; row 2 right, stretched;
row 3 left, split; row 3 right, next cycle

4. CONCLUSION

The paper presents a technical overview of the podded propeller projects titled “Systematic Investigation of Azimuthing Podded Propeller Performance” jointly undertaken 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 current paper presents a brief overview of the experiments investigations pursued under that project.

The work addressed gaps in the knowledge concerning podded propeller performance, performance prediction, and performance evaluation. Amongst the hydrodynamic issues that have been addressed are questions regarding the effects of hub taper angle, pod-strut configuration, wake-strut interactions, gap pressure, pod geometry, pod gap effect and static azimuthing conditions on podded propulsor performance.

All of the measurements and the sub sequential analyses and interpretations showed consistency and supported general hydrodynamic principles.

5. ACKNOWLEDGEMENT

The authors thank the Natural Sciences and Engineering Research Council (NSERC) Canada, the National Research Council (NRC), Oceanic Consulting Corp., Thordon Bearings Inc., and Memorial University for their financial and other support. Thanks are also extended to Jim Gosse and other technical service staff of Memorial University.

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