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Numerical hydrodynamic evaluation of propeller (with hub taper) and podded drive in azimuthing conditions

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ABSTRACT

This paper aims to predict the hydrodynamic forces on a propeller with different hub taper angles and a podded drive unit in azimuthing conditions. In order to evaluate the propulsive performance of the podded drive system, a Reynolds-Averaged Navier Stokes (RANS) solver is employed. The method has been first verified by a single propeller with different hub taper angles. The performance curves of the propellers, obtained by numerical methods, have been compared to and validated with experimental results. In the next step, the method has been extended to the podded drive unit for both puller and pusher configurations. The yaw angles of the podded drives are set to vary from -30° to $+30^{\circ}$ with 5° increments. The propulsive characteristics, including the torque and thrust of the propeller, the axial force, and the side force of the unit are presented as functions of the advance velocity ratio and yaw angle. Computational results are compared to the available experimental data. Finally, it is shown there is good agreement between the experimental measurements and the results of the present numerical method.

1. Introduction

It was in the 1990s when podded drive propulsion systems aroused great interest. Since then, these propulsion systems are being widely used in the marine industry and even becoming more and more popular, not only in passenger ships, but also in offshore drilling units and naval vessels. The podded drives offer many advantages over conventional propulsion systems, such as more uniform flow, improved maneuverability, enhanced seakeeping performance characteristics, lower noise and vibration, less fuel consumption, space saving advantages in ship architecture and arrangement, and rudder and shaft elimination (Carlton, 2007, Sarioz et al., 2005). The main components of podded drive systems include the strut, the pod and the propeller. However, some systems may utilize steerable flaps as an additional component connected to the strut for course keeping. Basically, the podded systems have two main configurations of the puller and pusher types. A schematic view of the puller and pusher podded drive types is presented in Fig. 1. In the puller type, the propeller is located on the upstream side of the pod and the strut. In the pusher type, the propeller is located on the downstream side of the pod and the strut. The Schottel type podded drive system (a combination of the puller and pusher types) is also employed in some vessels. The trailing and leading propellers at either end of the Schottel-type drive are rotated in opposite directions to recover power lost in the wake.

The prediction of the podded drive system propulsive characteristics is strongly correlated to the accuracy of the calculation of hydrodynamic forces acting under various working conditions. In azimuthing conditions, there is a strong interaction between the rotating part (propeller) and the fixed parts (pod and strut) of podded drive systems. These hydrodynamic forces can be important from both a structural and an operational perspective. For instance, bearing failure is one of the main operational problems of the podded drive systems (Carlton, 2008) and occurs when there are significant fluctuations in forces and moments on the podded drive system especially in yaw angle. Therefore, studies for prediction of the hydrodynamic forces acting on a podded drive system in azimuthing conditions are of great importance and interest for the design of such systems.

Recently, several researchers (Reichel, 2007, Islam et al., 2009, Liu et al., 2009, and Amini and Steen (2011)-12) have explored this subject and much effort has been dedicated to study and understand the various aspects and characteristics of such systems, both numerically and experimentally. For example, a comprehensive experimental and numerical analysis was carried out at Memorial University. Particular test equipment was designed and several different measurements were also considered. The podded drive

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Nomenclature

D	Propeller diameter
F_x	Axial force
F_y	Side force
J	Propeller advance velocity ratio
k	Turbulence kinetic energy
K_Q	Propeller torque coefficient
K_T	Propeller thrust coefficient
K_{fx}	Axial force coefficient
K_{fy}	Side force coefficient
n	Propeller rotational velocity
P	Static pressure
Q	Propeller torque
T	Propeller thrust
V	Axial velocity
$\vec{v}$	Velocity vector
δ_{ij}	Keronecker delta
η_{pro}	Propeller efficiency
η_{unit}	Total unit efficiency
μ	Molecular viscosity
ρ	Fluid density
ω	Turbulent dissipation rate
ψ	Yaw angle
$\overline{\overline{\tau}}$	Stress tensor

system was tested in the puller and the pusher conditions in different yaw angles ranging from -30° to $+30^{\circ}$. In a complementary study, Liu et al. (2009) applied a propeller panel method code for prediction steady and unsteady forces, torques and bending moments at various azimuth angles.

Three numerical approaches are employed for the evaluation of the propulsive performance of podded drive systems; the potential method; the hybrid method; and the viscous method. The numerical methods based on potential flow theory have been widely and successfully used to predict the performance of conventional propellers. The modified wake model should be implemented in order to predict the performance of podded propellers using the numerical methods based on potential flow. Achkinadze et al. (2003) presented a velocity-based panel method improved with semi-empirical viscosity corrections for the lift and drag of propeller blade and strut sections. Also, Ghassemi and Ghadimi (2008) predicted podded drive performance by applying the potential flow method. At large yaw angles, there is an apparent discrepancy between numerical results obtained by using the potential flow method and experimental data. For this reason, the results achieved through the potential flow method should be corrected at large yaw angles in order to deliver proper values for pod drag.

In addition, different hybrid methods have been applied to study the flow characteristics around podded drive systems and the hydrodynamic interaction between the propeller, the pod, and the strut. In a hybrid potential/viscous approach, the flow around the propeller is simulated by BEM (boundary element method) or the VLM (vortex lattice method) and the pod and strut are modeled by RANS or Euler solvers. Considerable work has been completed on the application of hybrid methods in podded propeller analysis. The studies by Gupta (2004), Mishra (2005) and Bal and Guner (2009) have contributed significantly to the field.

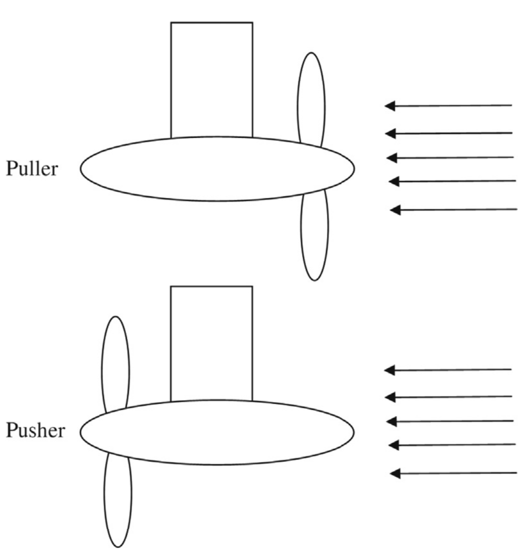

Fig. 1. The scheme of a puller and pusher podded drive.

Due to viscous effects at large yaw angles, the interaction between the propeller, the pod, and the strut is enhanced. Furthermore, the drag forces of the propeller, the pod, and the strut increase greatly at these angles as a result of flow separation. Viscous solvers are capable of taking into account the viscous and turbulence effects for podded drive systems. Hence, the viscous solvers are among appropriate methods in studies related to the propulsive performance of a podded drive in azimuthing conditions. Viscous methods based on RANS formulation have been applied to the podded propeller in straight condition; however, there is a lack of research and study on the evaluation of hydrodynamic forces on the podded drives in azimuthing conditions with RANS method.

RANS viscous simulation for the podded drives was first introduced by Sanchez-Caja et al. (1999) who presented a fully viscous method for their analysis. Ohashi and Hino (2004) also studied this problem using a RANS solver with unstructured mesh. Junglewitz and El Moctar (2004) investigated the interaction between the components of the podded drive system in azimuthing conditions. Recently, Koushan and Krasilnikov (2008), Guo et al. (2009), Amini, et al. 2012, Arikan et al. (2012) and Shamsi and Ghassemi, (in press) used steady and unsteady RANS solvers for simulating the flow around pulling and pushing podded propeller with yaw angle.

This study aims to provide insights into the propulsive characteristics of podded propulsors in azimuthing conditions using the RANS method. The present work is divided into two sections. The first section refers to the evaluation of the propulsive performance of the single propeller with different hub taper angles by means of the RANS method. In the next section, the performance of the puller and pusher types of podded drive are investigated at different speeds and different azimuthing angles. Finally, the calculated results are validated through a comparison with the experimental data measured at Memorial University.

2. Mathematical formulation

2.1. Governing equations

In this study, it is assumed that the fluid is incompressible. The governing equations are the mass and momentum conservations.