Ocean Engineering 36 (2009) 1003–1014

Contents lists available at ScienceDirect

Ocean Engineering

journal homepage: www.elsevier.com/locate/oceaneng

Unsteady hydromechanics of a steering podded propeller unit

Pengfei Liu [a,*], Mohammed Islam [b], Brian Veitch [c]

[a] National Research Council Canada, Institute for Ocean Technology, 1 Kerwin Place and Arctic Avenue, St. John's, NL, Canada A1B 3T5
[b] Oceanic Consulting Corporation, 95 Bonaventure Avenue, St. John's, NL, Canada A1B 2X5
[c] Faculty of Engineering & Applied Sciences, Memorial University of Newfoundland, St. John's, NL, Canada A1B 3X5

ARTICLE INFO

Article history:
Received 17 January 2009
Accepted 13 May 2009
Available online 18 June 2009

Keywords:
Propeller shaft dynamic response
Podded propulsors
Maneuvering and steering dynamics
Propulsion simulator
Unsteady panel method

ABSTRACT

Unsteady forces, torques and bending moments were predicted for a model podded propulsor unit at various azimuth angles. Predictions in time history include propeller shaft thrust, propulsor unit thrust, normal forces to the propeller shaft bearing, total forces acting on the propulsor unit, propeller shaft torque, blade spindle torque, in-plane and out-of-plane bending moments, and propulsor unit stock shaft torque and bending moments. Analysis was performed for averaged forces and their fluctuations as well. A time-domain unsteady multi-body panel method code, PROPELLA, was further developed for this prediction work. Predictions were compared with a set of time averaged in-house experimental data for a puller-type podded propulsor configuration in the first quadrant operation. Unsteady fluctuations of forces were predicted numerically. Analysis was made for the bending moment on propeller blades, shaft and the propulsor unit stock shaft for azimuth angles from 0° to 45°. It indicates that the magnitude and fluctuation of the forces are significant and they are essential for structural strength and design optimization. The predicted bending moment and global forces on the propulsor unit provide some useful data for ship maneuvering motion and simulation in off-design conditions.

1. Introduction

Research and development on propulsion hydrodynamics prediction, design optimization and performance evaluation for traditional marine propellers are extensive in the literature. Among these, the first attempt of using panel method for a propeller was made in the mid-1980s (Hess and Valarezo, 1985), and examples of panel method application to marine propellers include those studies performed at MIT (Kerwin et al., 1987) and Mitsubishi (Hoshino, 1993) to name but two. However, R&D activities for the podded propulsor units first became noticeable only since around 2000. With a dramatic increase in application and installation of podded propulsors, structural and bearing failures became prevalent and hydrodynamic design optimization became important. Therefore, systematic research and development work, both experimentally and numerically, became necessary. Prior to the mid-2000s, R&D work on podded propulsors was mostly performed by individual shipbuilders internally. Published results were rare. To address these issues, a collaborative R&D program was initialized in 2001 among Memorial University of Newfoundland (MUN), Institute for Ocean Technology (IOT) of National Research Council Canada (NRC), Oceanic Consulting Corporation and Thordon Bearing Ltd.

The podded propeller research program contains both experimental and numerical components. The goal of the numerical work is to develop a robust and reliable numerical tool with a suite of capabilities to perform tasks such as propulsive characteristics and unsteady structural load prediction, and performance evaluation and design optimization of podded propeller units. In the past seven years, a propeller panel method code, PROPELLA, was further developed and used as the main prediction tool to address the needs for podded propulsor simulations. Numerical tools need verification and validation before they can be used. However, verification and validation with good agreement with analytical and experimental measurements are not the ultimate goals of numerical work. This numerical tool, in addition to being able to produce the same kind of results as from experimental measurements in a cost effective and timely fashion, was used to produce important results that are impossible or difficult to obtain from experimental measurements. These results include unsteady propeller blade spindle torque, in-plane and out-of-plane bending moments about arbitrary axes, and the propulsor unit's transient global force and moments with respect to any arbitrary axes.

The hydrodynamics kernel of the code is a classical panel method. It is a low-order time-domain panel method similar to many other panel methods, such as PMARC developed at NASA Ames Research Centre (Katz and Plotkin, 1991). The backbone of the current panel method code was initially developed to simulate marine swimmers with lunate tails (Liu, 1996a; Liu and Bose,

* Corresponding author. Tel.: +1 709 772 4575; fax: +1 709 772 2462.
E-mail address: pengfei.liu@nrc-cnrc.gc.ca (P. Liu).

0029-8018/$ - see front matter
doi:10.1016/j.oceaneng.2009.05.012

Nomenclature

X_g	x-axis of the global or inertia frame
Y_g	y-axis of the global or inertia frame
Z_g	z-axis of the global or inertia frame
X_b	x-axis of the propeller body frame
Y_b	y-axis of the propeller body frame
Z_b	z-axis of the propeller body frame
α	rotational angle of propeller body frame about its X_b-axis (roll)
β	rotational angle of propeller body frame about its Y_b-axis (pitch)
θ	rotational angle of propeller body frame about its Z_b-axis (azimuth or yaw)
D	diameter of propeller
EAR	expanded area ratio of propeller blades
h_D	hub diameter to blade diameter ratio
J	propeller shaft advance coefficient ($J = V_{prop}/nD$)
J_{ship}	ship advance coefficient ($J_{ship} = V_{ship}/nD = J/\cos(\beta)\cos(\theta)$)
K_t	shaft thrust coefficient ($K_t = T/\rho n^2 D^4$)
K_q	shaft torque coefficient ($K_q = Q/\rho n^2 D^5$)
K_{sp}	blade spindle torque coefficient ($K_{sp} = Q_{sp}/\rho n^2 D^5$)
K_{ip}	blade in-plane bending moment ($K_{ip} = Q_{ip}/\rho n^2 D^5$)
K_{op}	blade out-of-plane bending moment ($K_{op} = Q_{op}/\rho n^2 D^5$)
M_x	propeller–pod–strut unit stock bearing bending moment coefficient ($M_x = Q_x/\rho n^2 D^5$)
M_y	propeller–pod–strut unit stock bearing bending moment coefficient ($M_y = Q_y/\rho n^2 D^5$)
M_z	propeller–pod–strut unit stock bearing steering torque coefficient ($M_z = Q_z/\rho n^2 D^5$)
M_{x_exp}	propulsor unit stock bearing bending moment coefficient defined in experiments
M_{y_exp}	propulsor unit stock bearing bending moment coefficient defined in experiments
M_{z_exp}	propulsor unit stock bearing steering torque coefficient defined in experiments
F_x	x-component of the propeller–pod–strut unit force
F_y	y-component of the propeller–pod–strut unit force
F_z	z-component of the propeller–pod–strut unit force
n	shaft rotational speed (rps)
p	absolute pitch value at local radius r
p_D	normalized pitch (p/D) at local radius r
ρ	fluid density
Q	moment or torque
r	blade section local radius
R	blade radius
T	thrust
V_{ship}	ship advance speed

1997; Liu and Bose, 1999). The code PROPELLA was then developed for an ice-class propeller research program (Liu, 1996b; Veitch et al., 1997). Inflow wake and hyperboloid panel algorithm were implemented to deal with oblique flow for highly skewed propellers (Liu and Bose, 1998). A semi-empirical cavitation model was developed to predict propeller cavitation performance (Liu et al., 2001a). In the meantime, automated surface mesh generation of arbitrary configuration was implemented for a propeller to interact with rudder, nozzle, ice blockage, etc. along with induced velocity downstream and wake roll-up (Liu et al., 2001b). A 3D unsteady data visualization scheme using MFC (C++) and OpenGL was implemented as well (Liu, 2002). A more robust and reliable iterative pressure Kutta condition using Broyden's method, rather than the traditional Newton–Raphson method, was developed in the early 2000s (Liu et al., 2002). Podded propeller geometry was implemented and a comparative study between puller and pusher type podded propulsors was performed at the initial stage of the research program (Islam, 2004; Islam et al., 2006). A shed vortex impingement algorithm was developed recently (He et al., 2007a, 2007b) and was validated via an in-house experimental research program (He et al., 2005). A multiple-lifting-object formulation was developed and used for wing-in-ground thruster simulation in 2005 (Liu, 2005). A propeller design and optimization procedure was developed and applied to a Canadian Coast Guard ice breaker, a dual-tunnel shallow hull Eckaloo (Liu et al., 2006). This multiple-body multiple-path panel method was extended for propeller and ice interaction recently (Liu et al., 2008).

Time averaged blade and pod unit stock forces of a podded propulsor at an azimuth angle during maneuvering for pusher and puller configurations were obtained in-house via experimental measurements only recently (Islam et al., to be submitted). These, to the authors' knowledge, are the first set of results available in the open literature. These time average forces give an indication of the structural loading of the podded propeller units and its components and are essential for numerical code validation. The main purpose of the current work is to obtain unsteady force fluctuation for structural strength evaluation and design consideration in terms of bearings and shaft/stock fatigue failure and structural strength analysis. The predicted forces and torques/moments and their fluctuations are also the basic data for the estimate of ship motion during maneuvering. In the following sections, we will briefly discuss code implementation, and validation against the time averaged forces of a podded propeller unit and its shaft components. Predictions of both time averaged and real-time fluctuations of the forces, torques and moments on the shaft and stock of the podded propeller units are then shown and analyzed.

2. Numerical method and implementation note

The hydrodynamic kernel of the code is a low-order, potential follow based time-domain panel method. An introduction to the method was discussed systematically by Katz and Plotkin (1991). A detailed formulation of this boundary element method in a general and in multiple-object and multiple-path format was presented in Liu (1996a) and Liu and Bose (1997), respectively. A detailed algorithm implementation of the multiple-object, multiple-path panel method to simulate interaction between propeller and other objects was given for an ice-class propeller approaching and interacting with an ice blockage (Liu et al., 2008).

The code was implemented by assuming that multiple objects are moving in their different paths in an acquiescent fluid. At each time step, the body frame of the podded propeller moves forward with a distance δd, and rotates about its shaft centre with $\delta\alpha$. At the same time step, the translated and rotated propeller body frame is further rotated about a transversal axis passing through the origin of the body frame with a constant angle of β to obtain a desired shaft inclination angle (the trim angle $\beta = 0$ for the podded propeller in this study). The final rotation about the centreline of the stock of the podded propeller unit is then made, with a constant value of θ to simulate a fixed azimuth angle