+ MODEL
ARTICLE IN PRESS
+ MODEL
Available online at www.sciencedirect.com
ScienceDirect
Publishing Services by Elsevier
International Journal of Naval Architecture and Ocean Engineering xx (2017) 1—13
http://www.journals.elsevier.com/international-journal-of-naval-architecture-and-ocean-engineering/

A numerical study on the correlation between the evolution of propeller trailing vortex wake and skew of propellers

Lian-Zhou Wang, Chun-Yu Guo*, Yu-Min Su, Tie-Cheng Wu

College of Shipbuilding Engineering, Harbin Engineering University, Harbin, 150001, China

Received 13 October 2016; revised 29 June 2017; accepted 10 July 2017
Available online ■ ■ ■

Abstract

The characteristics of the relationship between the evolution of propeller trailing vortex wake and skew angle are numerically examined based on four different five-blade David Taylor Model Basin (DTMB) model propellers with different skew angles. Numerical simulations are based on Reynolds-averaged Navier—Stokes (RANS) equations combined with SST $k-\omega$ turbulence model. Results show that the contraction of propeller trailing vortex wake can be restrained by increasing skew angle and loading conditions, and root vortices fade away when the propeller skew angle increases. With the increase of the propeller's skew angle, the deformation of the hub vortex and destabilization of the tip vortices are weakening gradually because the blade-to-blade interaction becomes weaker. The transition trailing vortex wake from stability to instability is restrained when the skew increases. Furthermore, analyses of tip vortice trajectories show that the increasing skew can reduce the difference in trailing vortex wake contraction under different loading conditions.
Copyright © 2017 Society of Naval Architects of Korea. Production and hosting by Elsevier B.V. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

Keywords: Propeller; Skew angles; Tip vortices; Hub vortex; RANS

1. Introduction

Propeller action is the main propulsion mode of modern ships, and the performance of propellers is a perennial subject of research. The mechanics of the propeller trailing vortex wake play important roles in engineering applications due to a direct correlation to the hydrodynamic performance, vibration, noise, and structural problems of modern ships (Felli et al., 2011). Physically, the characteristics of propeller trailing vortex wake are strictly related to the factor that causes energy loss due to cavitation, vibration, and noise. For the propellers working behind modern surface ships, the performance of a propeller varies greatly with motions induced by environment (due to, for example, waves, wind, and currents). As a result, a propeller must function in a range of working conditions, which puts forward higher requirements for the marine propellers, and the conventional propellers can hardly satisfy the demands of modern civil ships and warships, so the propellers with complicated geometry have been widely used. For example, propellers with a high skew angle are much more efficient than conventional propellers (Ghasseni and Ghadimi, 2011; Zhu, 2015). Modern propellers with complicated geometry result in the wake behind a propeller becoming more complex. Therefore, the design of the propeller should enhance performance, and in order to accomplish this, an accurate trailing vortex wake analysis process is required to discover the correlation between propeller trailing vortex wake and the geometrical parameters of the propeller. This, in turn, can help explain the mechanics of the propeller trailing vortex wake. Many researchers have investigated the evolution of propeller trailing vortex wake based on detailed experiments, however, these experiments seldom investigate the correlation between propeller trailing vortex wake and geometrical parameters of the propeller.

* Corresponding author. College of Shipbuilding Engineering, Harbin Engineering University, 145 Nantong Street, Harbin, 150001, China. Fax: +86 0451 82518417.
E-mail address: guochunyu_heu@outlook.com (C.-Y. Guo).
Peer review under responsibility of Society of Naval Architects of Korea.

http://dx.doi.org/10.1016/j.ijnaoe.2017.07.001
2092-6782/Copyright © 2017 Society of Naval Architects of Korea. Production and hosting by Elsevier B.V. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

Please cite this article in press as: Wang, L.-Z., et al., A numerical study on the correlation between the evolution of propeller trailing vortex wake and skew of propellers, International Journal of Naval Architecture and Ocean Engineering (2017), http://dx.doi.org/10.1016/j.ijnaoe.2017.07.001

To investigate the spatial and temporal evolution of the trailing vortex wake of a marine propeller, Di Felice et al. (2004) employed a Particle Image Velocimetry (PIV) technique to analyze this evolution under different operating conditions. The results of their study show a significant decrease in the level of turbulence from the tip vortices. A weaker dissipation of the blade trailing vortex wake turbulence was observed when decreasing the blade loading. The development of the slipstream instability and the breakdown of the hub and tip vortices were outlined by the far trailing vortex wake.

Felli et al. (2006) examined the propeller trailing vortex wake in detail based on experimental measurements. The velocity field and the pressure field of the propeller trailing vortex wake were discussed in the study. They concluded that the pressure field of the propeller trailing vortex wake is mainly caused by tip vortex in the near field. The sudden breakdown process of the vortices is the reason of the hub vortex distortion, which relates to the pressure field at the shaft rate frequency.

Paik et al. (2007) utilized the PIV technique to study the trailing vortex wake characteristics of a marine propeller. The results show that the distribution of radial vorticity has connection with the loading distribution of the propeller blades. The strong contraction of the propeller trailing vortex wake mainly happens in the region of $X/D = 0.53$, after strong contraction, the trajectory formation shows irregular oscillation. The hub vortex can help to obtain much information about the propeller trailing vortex wake system because the hub vortex can be easily captured.

Felli et al. (2008) investigated the issues of propeller trailing vortex wake evolution and instability using the propellers with different numbers of blades. The Laser Doppler Velocimetry (LDV) technique was employed to make the trailing vortex wake measurement. The mechanism of the breakdown process of tip vortices and hub vortex was discussed in detail in the study. Results show that the problem of trailing vortex wake instability has more to do with the vortex—vortex interaction. The phenomenon of tip vortices grouping is a typical characteristic of propellers, which is the result of the interaction between continues filaments.

Felli et al. (2011) conducted a discussion on effect of the spiral-to-spiral distance and the number of blades on the destabilization and evolution of the tip and hub vortices in the transition and the far trailing vortex wake. Detailed timed visualizations and velocimetry measurements were used. The results show that the vortex breakdown phenomena observed in the experiment was caused by the mutual interaction between adjacent spirals that were altered by employing a series of propellers with different number of blades.

With the advances of technology, basic issues of fluid mechanics in propulsion research are transforming from obtaining traditional macroscopic force and moment to measuring the detailed flow field. In order to obtain the details of fluid flow, researchers have attempted to discover the most fundamental attributes that cause an object's motion to change. After the 25th ITTC, a specialist committee was set up on detailed flow measurement, which has brought together experts and scholars dedicated to basic fluid mechanics research to resolve these problems (Toda, 2008). Obtaining detailed flow is especially important to reveal the mechanism and physical phenomenon of fluids for propulsion research. However, CFD is more efficient and has lower costs than the Experimental Fluid Dynamics (EFD) and can acquire more detail information about flow field (Sun et al., 2016; Wang et al., 2014), but most CFD calculations about propellers are mainly concerning about the applicability of turbulence modeling and the performance under off-design conditions.

Jang and Mahesh (2013) studied the flow characteristics of a propeller which rotates in the reverse direction based on the Large Eddy Simulation (LES) method. They found that the heavy propeller loads were mainly caused by the flow separation and the heavy propeller loads could decrease the reverse flow. Muscari et al. (2013) analyzed the effects of different turbulence modeling approaches for simulating the propeller trailing vortex wake. The limits and capabilities of RANSE modeling and Detached Eddy Simulation (DES) modeling were discussed when dealing with the propeller trailing vortex wake. Using a dynamically overlapping grid approach, Dubbioso et al. (2013) studied the hydrodynamic performance of a propeller working in oblique flows. They analyzed two loading conditions at diverse incidence angles. Di Mascio et al. (2014) investigated the trailing vortex wake instability of a propeller working in oblique flows based on DES method. The destabilization was examined by the calculations of propeller working in pure flow and drift. Baek et al. (2015) numerically investigated the trailing vortex wake features of a marine propeller under different loading conditions based on RANS method. They explored laws that the velocity fields and the 3-D vortical structures varied with advanced ratios. The empirical models of the 3-D helices of tip vortices were also proposed in the research.

Overall, most current studies seldom investigate the correlation between propeller trailing vortex wake and the geometrical parameters of the propeller. Therefore, this paper focuses on finding out the relationship between the evolution of propeller trailing vortex wake and the skew angle based on four different DTMB propellers with varying skew angles. The correlation between the characteristics of propeller trailing vortex wake and the propeller skew is analyzed in detail by RANS equations and SST $k-\omega$ turbulence model.

2. Mathematical model

2.1. Governing equations

The numerical simulations completed in this work are based on RANS equations. The three-dimensional incompressible continuity and momentum equations with RANS approximation are described as:

$$\frac{\partial u_i}{\partial x_i} = 0 \tag{1}$$

Please cite this article in press as: Wang, L.-Z., et al., A numerical study on the correlation between the evolution of propeller trailing vortex wake and skew of propellers, International Journal of Naval Architecture and Ocean Engineering (2017), http://dx.doi.org/10.1016/j.ijnaoe.2017.07.001

Download English Version:

https://daneshyari.com/en/article/8864968

Download Persian Version:

https://daneshyari.com/article/8864968

Daneshyari.com