Numerical simulation of open-water characteristics and cavitation performance for a highly skewed propeller
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ABSTRACT
It is essential to predict the propeller cavitation in an early stage for proper design of the propulsion system. The current study focuses on the open-water characteristics and cavitation performance of the Postdam Propeller Test Case (PPTC) by Reynolds-averaged Navier-Stokes method (RANS). The results are grid independent when using the grid resolution with $30 \leq y^+ \leq 80$ in the near-wall region, and RNG k-ε turbulence model can predict reasonable results with less effort. It can capture the steady sheet cavitation and root cavitation, but failing in the vortex tip cavitation prediction, indicating methodologies involving high resolution of turbulence behaviors are demanded.

KEY WORDS: Highly skewed propeller; open-water characteristics; sheet cavitation; root cavitation; RANS.

INTRODUCTION
The prediction of propeller cavitation and its adverse effects attracts increasingly attention in maritime engineering. Cavitation inevitably occurs on the propeller with the continuous development of high-speed and high-power vessels. It can not only cause thrust and torque reduction and decrease of hydrodynamic efficiency, but also induce cavitation noise and cavitation vibration, threatening stealthiness of military vessels and affecting marine life. Furthermore, severe damage to the propeller blades and even the appendages after propeller may be caused by cavitation induced unsteady dynamics. It is necessary to predict cavitation and analyze the corresponding consequences at an early design stage, ensuring the successful optimization of propulsors and aftbody configurations.

The research on the cavitation flow of propeller has received extensive attention in recent years due to the concern of underwater noise. At present, the numerical simulations of propeller cavitation flow or unsteady cloudy cavitation are often carried out by the RANS method with two equation turbulence model and cavitation model based on the Raleigh-Plesset bubble dynamics equation (Li, 2009; Li, 2012; Li et al., 2015; Liu, 2011). Kawamura et al. (2005) used the Reynolds stress and the SST turbulence model combined with the Zwart cavitation model to calculate the SEIUN-MARU highly skewed propeller. The difference between the calculated pressure fluctuations and the experimental results is less than 20%, which can meet the requirement of the current engineering application.

In 2011, SMP2011 committee had a special arrangement for the numerical simulation of propeller and the hydrofoil cavitation. The Postdam propeller test case (PPTC) has been chosen as the benchmark example for examination of the open-water characteristics and cavitation performance. This propeller is a large-side oblique propeller, which is both longitudinal and lateral. The related experiments were done by SVA, and the related test results were published after the symposium SMP2011.

In this paper, the open-water characteristics and cavitation performance of the highly skewed propeller PPTC was chosen as the research object. Firstly, the open-water characteristics of the propeller for different advance coefficients are calculated based on the two-phase Reynolds-averaged Navier-Stokes equations (RANSE). The effects of turbulence models and grid density on the results are analyzed by comparison of the thrust and torque coefficients of the propeller with numerical and experimental results published on SMP 2011 workshop. It is found that the results are grid independent when using the current grid topology and grid resolution with $30 \leq y^+ \leq 80$ in the near-wall region, and RANSE with RNG k-ε turbulence model can predict reasonable results with less effort.

Then it carries out the numerical simulation of the propeller in cavitating flow with advance coefficient $J=1.019$ and cavitation number of $\pi=2.024$. It is found that a steady sheet cavitation can be observed at the suction side from 0.975R extends up to the blade tip and a root cavitation can also be predicted, which is in accordance with experimental observations. However, the tip vortex cavitation which has been observed in experiments could not be predicted by the current approach. It seems that further refinement of grid around the tip region or other methodologies involving high resolution of turbulence