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Numerical analysis and performance comparison of the same series of composite propellers

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ABSTRACT

Composite marine propeller, due to its potential advantage of reduced weight and noise reduction, has increasingly attracted the attention of researchers. In the current work, the performance and efficiency of the 438x series of composite propellers are studied based on the finite element method (FEM) and the computational fluid dynamics method (CFD). The influence of blade skew angle on the hydro-elastic performance, cavitation and efficiency of composite marine propeller are discussed. The performance differences are compared between composites series propellers and metal series propellers. According to the performance characteristics of the same series of composite propellers, a fast and effective design method is proposed.

1. Introduction

Traditionally metallic propellers are subject to corrosion and cavitation damage, fatigue-induced cracking, and have relatively poor acoustic damping properties that can lead to noise (Mouritz et al., 2001). In recent years, the potential benefits of composites play an important role in improving the performance of marine propeller, especially for large size and high performance ships requiring weight loss, vibration and noise reduction. In the literature composite propeller has been shown to a weight of only one-third the weight of conventional Nickel-Aluminum Bronze (NAB), reducing the propeller noise typically by 5 dB, and reducing the fuel consumption by up to 15% by using the hydro-elasticity to optimize propulsive efficiency (George, 2004).

In recent years, a considerable amount of research has been completed on composite marine propellers. Lin (1991a, 1991b) calculated the stress of a composite blade under the fluid pressure and centrifugal loads using the commercial finite element software ABAQUS, and compared with a geometrically identical isotropic metal propeller. The composite blade was composed of multiple layers of braided fiber and a foam-filled core, the fluid pressure and centrifugal loads were considered using PSF-2 program (a software program for analyzing the flow field of a propeller in steady and subcavitating flows). Subsequently, Lee and Lin (2004); Lin et al., (2009) studied the optimized design method of the composite blade using the genetic algorithm, and completed the corresponding experiment in subsequent study. Lin and Lin (2005); Lin and Tsai (2008) developed a coupled 3-D FEM/VLM (Vortex-lattice Methods) method for analyzing composite propeller in steady flow, the strength and the underwater free vibration of the composite blade were analyzed. At the same time, Motley et al. (2009), Motley and Young (2011), Young (2008, 2010), and Liu and Young (2009) presented a coupled FEM/BEM (Boundary Element Method) approach to comprehensively investigate flexible composite propellers in subcavitating and cavitating flows. The hydrodynamic performance and efficiency were improved by utilizing the bend–twist coupling effects of composites. Recently, Paik et al. (2013) studied the performance characteristics of three kinds of flexible propellers, and tested and analyzed the tip vortex cavitation and the acoustic noise performances. Herath and Prusty et al. (Mulcahy et al., 2010; Herath et al., 2013, 2015) presented a layup optimization algorithm for composite marine propeller. The off-design propulsive efficiency was improved by using the Finite Element Method combined with Genetic Algorithm (GA). Shenoi et al. (Weitzenböck et al., 1999a, 1999b; Xing et al., 2004) discussed the manufacturing aspects of composite blades. Lee et al. (2015) analyzed the usability of reverse engineering with steady analysis and the possibility of performance optimization at off-dsesign conditions by using the BEM/FEM-based method.

Based on the above outstanding research, this paper will further study the hydro-elastic performance, cavitation and efficiency of the same

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Notation

$[A]$	The angular velocity matrix
B	Linear strain-displacement transformation matrices
B_L	Nonlinear strain-displacement transformation matrices
D	Propeller diameter
D_m	Material property matrix
$\{F_h\}$	Generalized fluid force normal to the surface of the blade
$\{F_r\}$	Centrifugal force
G	A matrix defined purely in terms of coordinates
J	Advance coefficient
K_T	Thrust coefficient
K_Q	Torque coefficient
$[K_l]$	Linear stiffness matrix
$[K_0]$	Initial displacement matrix
$[K_g]$	Geometric matrix
$[K_r]$	Rotational stiffness matrix
m	Outward normal vector
n	Propeller rotating velocity
$[N]$	Displacement interpolation matrix
P_o	Static pressure
P_k	Vapor pressure
P	The total hydrodynamic acting on the blade
P_r	The hydrodynamic pressure due to rigid-blade rotation
P_v	The hydrodynamic pressure due to elastic blade deformation
Q	Propeller torque
R	Propeller radius
T	Propeller thrust
$\{u\}$	Nodal displacement vectors
V_A	Speed of advance of propeller

Greek alphabet

Ω	Rotating constant angular velocity
η	Propeller efficiency
ρ	Density of water
ρ_m	Density of the material of the blade
σ	Cavitation number

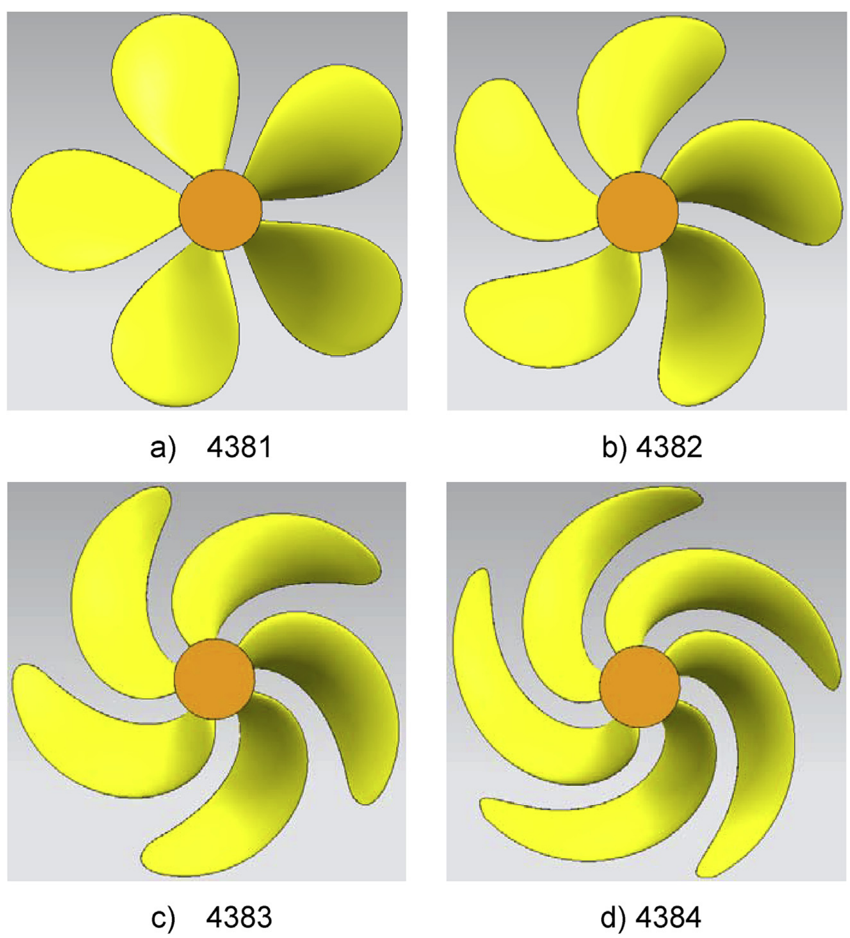

Fig. 1. The geometries of the 438x series propeller.

series of composite propellers. For the research of the same series of propellers, especially the same series of metal propellers, has carried out a lot of work in the past. However, there are significant differences in material properties between the metal and the composite, so this is particularly important to study the performances of the same series of composite propellers. For the same series of metal propellers, the designers found that the geometrical features, such as propeller diameter, skew, pitch distribution et al., are the main factors that affect the