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Seakeeping Analysis of a Wave-Piercing Catamaran Using URANS-Based Method

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Wave-piercing catamarans (WPCs) consist of two demihulls with wave-piercing bows that may immerse into or emerge out of the free surface when advancing in waves. Therefore, it is questionable whether linear theories like modified strip theory (STF) can precisely predict the seakeeping performance of WPCs in general cases. In this paper, the unsteady Reynolds-averaged Navier–Stokes equations (URANS) method is used to predict the pitch and heave motions of WPCs under various speeds and wave frequencies in head seas, while the STF method is employed for comparison. Furthermore, some parametric studies, such as modifying the shape of wave-piercing bows, disregarding the interaction between demihulls, neglecting the viscosity of water, and altering wave steepness, are also carried out using the URANS-based method. Comparison of numerical and experimental results shows that, under the Froude numbers of interest ($0.3 \le F_n \le 0.6$), acceptable agreement is achieved by using the URANS-based method, while only a similar trend is obtained by using the STF method at the small Froude number $F_n = 0.3$. Based on the numerical results of parametric studies, it is shown that the effects of wave steepness and forward speed on the free surface are significant, while the viscous effect is unimportant to the heave and pitch motions.

NOMENCLATURE

B	Beam overall
b	Beam of demihulls
d	Distance between centers of two demihulls
F_n	Length as Froude number
k	Wave number
k_{yy}	Pitch radius of gyration
L	Length of water line
S	Model scaling
T	Draft
U	Forward speed
x_g	x coordinate of the center of gravity (from the stern)
z	Heave amplitude of the WPC
z_g	$z-$coordinate of the center of gravity (above the mean free surface)
θ	Pitch amplitude of the WPC
Φ	Roll amplitude of the WPC
Δ	Displacement
λ	Wavelength
ζ	Wave amplitude
ν	Kinematic viscosity
$k\zeta$	Wave steepness

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KEY WORDS: Wave-piercing catamaran (WPC), nonlinear, pitch, STF, URANS method, wave amplitude, high speed.

INTRODUCTION

A wave-piercing catamaran (WPC) is a high-performance multihull vessel with super slender bodies and penetrating bows. Compared with other high-speed marine vehicles, WPCs possess a remarkable advantage; that is, in rough seas they can pierce the wave rather than ride on it, which significantly reduces wave-added resistance and speed loss. Therefore, the maximum speed of a WPC is normally greater than 40 knots. However, the displacement and restoring force of the penetrating bows of a WPC are relatively small, causing a low seakeeping performance in moderate to rough sea conditions. Hence, seakeeping performance is one of most important characteristics of a WPC, and analysis methods for and optimization of seakeeping performance attract many researchers' attention.

Many studies have been carried out on the seakeeping problems of multihull ships, including WPCs, over the past decades. Most of them are based on experiments or linear theories. One of the most detailed experimental studies was accomplished by Soars (1993), who made various WPC proposals for model testing, including the seakeeping aspect under different wave headings and wave heights, and finally developed a WPC with superior performance. Matsubara et al. (2011) experimentally confirmed that the motions of a WPC are nonlinear because of the immersion of the center bow in large waves. Bouscasse et al. (2013) experimentally investigated a fast catamaran advancing in regular and irregular waves and assessed nonlinear effects on the hull motions.

As for the theoretical studies, strip theory and its modified form, STF, were the most widely employed methods for investigating the seakeeping motions of catamarans (Lee et al., 1973; Ohkusu and Wen, 1995; Deng and Ma, 2006; Holloway and Davis, 2006; French et al., 2012; Han et al., 2012; Zheng and Dong, 2012).