Ocean Engineering 146 (2017) 151–169

Contents lists available at ScienceDirect

Ocean Engineering

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

Numerical investigation into the interaction of resistance components for a series 60 catamaran

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ARTICLE INFO

Keywords:
Catamaran
Interference resistance
CFD
RANS
Separation

ABSTRACT

Numerical study of the flow around S60 catamaran and S60 monohull, as well as an investigation into interference phenomenon are performed within this paper. Numerical simulations of the free surface and double body viscous flow are carried out for six Froude numbers in the range 0.3–0.55, for four separation ratios in the range 0.226–0.4696 and for monohull. Verification and validation of the obtained results are provided. Validation is performed by comparison with available experimental data and satisfactory agreement is obtained. Firstly, catamaran interference resistance is studied through interference factor based on the total resistance of catamaran and monohull. Afterwards, the interference resistance is investigated through a procedure based on the resistance decomposition, in order to determine the viscous and wave interference effect on the total resistance of catamaran. The form factor for monohull is found to be different than the form factor for catamaran with identical demihulls. Also, form factor for catamaran is found to be in correlation with the separation. Analysing the flow around demihulls, it has been established that the strength of cross flow is correlated to interference resistance. Finally, benefits of CFD based on viscous flow as a tool in catamaran preliminary design are highlighted.

1. Introduction

Catamaran and other multihull configurations have a better performance regarding speed, resistance, manoeuvrability and transverse stability compared to monohull configurations. Thus, for the last few decades significant growth of interest for multihull vessels in civil, recreational and military fields can be noticed. Consequently, many theoretical, numerical and experimental investigations concerning multihull vessels have recently been made (Zaghi et al., 2010). Despite that, catamaran resistance prediction still has a degree of uncertainty (Sahoo et al., 2007). Spacing between hulls (separation) represents one of the most important parameters in catamaran design because of the hydrodynamic interaction between hulls operating in a proximity to each other. Therefore, this parameter must be taken into account at the design stage (Bari and Matveev, 2016). The wave field generated by a multihull vessel is not a simple superposition of the wave fields generated by each hull, if the hulls are sufficiently close to each other (Faltinsen, 2005). These wave fields usually strongly interfere and therefore can cause either favourable or unfavourable effects (Souto-Iglesias et al., 2012). The resulting wave pattern in the inner region is very complex and strongly affects hydrodynamic characteristics of a catamaran. Wake angle of catamaran wave pattern is narrower than Kelvin cusp angle (He et al., 2016). Also, wavelengths of the highest wave generated by catamaran and monohull vary considerably. The wavelength of the highest wave generated by a catamaran is approximately equal to the separation for values of Froude number (*Fn*) above 1, while the wavelength of the highest wave created by fast monohull ship is nearly equal to the beam of the ship for *Fn* values above 5 (Ma et al., 2016).

The resistance of a catamaran is different than double resistance of the monohull because of the appearance of interference resistance (Jamaluddin et al., 2012). Interference resistance can be divided into two components, i.e. viscous and wave interference resistance. Asymmetric flow around demihulls is the main cause of the viscous interference, since it changes formation of the boundary layer and the development of vortices. Wave interference is caused by the interference between wave system of each demihull (Insel and Molland, 1992). Many authors have investigated the influence of the separation on catamaran resistance and the interference resistance. While most of the authors have investigated catamaran resistance for catamaran models, Haase et al. (2016) developed a novel full-scale resistance prediction method for large medium-speed catamarans based on Computational Fluid Dynamics (CFD). The method assumes that pressure drag is independent of Reynolds number (*Rn*). The estimation of the full-scale resistance is derived from simulations at full-scale *Rn*. These simulations are made for model

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https://doi.org/10.1016/j.oceaneng.2017.09.043
Received 30 May 2017; Received in revised form 21 August 2017; Accepted 24 September 2017

speed, model dimensions and the initial model mesh with full-scale *Rn* obtained by changing the kinematic viscosity of the water.

Souto-Iglesias et al. (2007) carried out experimental investigation in the towing tank for one commercial monohull and catamaran model to investigate the influence of the separation on the interference resistance. In order to ascertain the accuracy of the conducted measurements, an uncertainty analysis was included. Results showed that catamarans with greater separation have wider range of favourable interference effects. This investigation was revisited using the same catamaran model (Souto-Iglesias et al., 2012). The effect of fixed and free model condition on the interference resistance was investigated. Also, extensive towing tank tests were carried out to investigate interference resistance for fixed and free S60 monohull and S60 catamaran model for different separations. The obtained results were compared with results published in (Yeung et al., 2004), where the authors proposed numerical procedure that is capable of rapid and accurate evaluation of the wave resistance of any monohull or combination of demihulls. Results showed that free model provided more extreme cases than fixed model for both favourable and unfavourable interference regimes. Broglia et al. (2014) found that the interference effects are more significant for narrower catamaran configurations and at intermediate values of *Fn*. They claimed that for smaller *Fn*, the wave elevation is too small and it does not affect the catamaran total resistance significantly. At higher values of *Fn*, wave system of each hull diverges and therefore superposition between them is considerably reduced. Thus, a catamaran starts to behave like a combination of almost non-interacting vessels. Authors also found that interference effects are strongly connected with sinkage and trim of a catamaran model.

As a result of advancement in computer science and numerical computation methods, improvement in accuracy and efficiency of CFD methods can be noticed. Consequently, an optimal choice to investigate hydrodynamic characteristics of catamaran becomes the combination of towing tank tests and CFD methods (Zha et al., 2015). Zhang et al. (2015) performed a validation of the Neuman-Michell theory. They highlighted the importance and robustness of this method for catamaran design. Reynolds averaged Navier-Stokes equations (RANSE) methods proved to be the most suitable for resistance prediction of medium-speed catamarans (Haase et al., 2013). Zha et al. (2015) carried out numerical simulations of viscous flow around catamaran model using the in-house RANSE solver naoe-FOAM-SJTU. Authors concluded that naoe-FOAM-SJTU is reliable software for solving general hydrodynamic problems with good efficiency and that is more flexible and extensible than commercial software. Broglia et al. (2011) carried out numerical simulations of viscous flow around catamaran and monohull models with the aim of studying the interference effects and their relationship with *Rn*. Catamaran and monohull models were fixed at the dynamic positions taken from the experiments. It was shown that dependence between interference effects and *Rn* is weak. In order to investigate dependence between interference effects and separation, Zaghi et al. (2011) performed extensive experimental and numerical investigations. Results of these investigations showed that interference, as well as maximum resistance coefficient, is higher for catamaran configurations with smaller separation. Also, maximum resistance coefficient for narrower catamaran configurations occurred at higher *Fn* values. Sarles et al. (2011) showed that section shape of demihull significantly affects the interference. Yengejeh et al. (2016) used RANSE solver to perform various viscous flow simulations around asymmetric planing hulls. Numerical simulations were performed for different separations, trim angles and *Fn*. Analysis of the obtained results showed that catamaran configuration has a significantly reduced wetted surface area than corresponding monohull having the same displacement. Utama et al. (2012) pointed out that interference effects due to separation and stagger are larger for symmetric catamaran hulls than for asymmetric ones. While most of the authors focused their research on catamaran configurations with the parallel hulls, Ebrahimi et al. (2014) studied a catamaran with non-parallel hulls. Authors indicated that for *Fn* below 0.8 catamarans with non-parallel hulls have larger total resistance, but for *Fn* above 0.8 these catamarans have smaller total resistance than catamarans with parallel hulls. Castiglione et al. (2014) showed that interference effects are more significant in shallow water than in deep water. He et al. (2015) demonstrated the applicability of Unsteady Reynolds Averaged Navier-Stokes (URANS) solver for the interference problems including the effects of sinkage and trim. They concluded that the main cause of the deviations in resistance, sinkage and trim using URANS solver is caused by the grid quality, but these numerical errors were found acceptable.

This paper contributes to the previous studies with the main goal to evaluate capabilities of CFD in numerical assessment of the interference resistance. Even though Insel and Molland (1992) divided interference resistance into two components, most of the authors nowadays investigate interference resistance through interference factor. For determination of interference factor, they use total resistance or wave resistance. Within this paper, influence of *Fn* and separation (s) on both components of interference resistance is investigated utilizing CFD. Benefits of CFD for assessment of interference resistance are highlighted. Simulations of viscous flow around S60 monohull and four S60 catamaran configurations are performed for six *Fn* values in the range $0.3 \leq Fn \leq 0.55$. Catamaran configurations differ in the separation and numerical simulations are performed for four separation ratios in the range $0.226 \leq s/L \leq 0.4696$. In order to determine both components of the interference resistance, free surface simulations as well as double body simulations are performed. Firstly, verification of numerically obtained results is made for simulation of free surface flow around the monohull and the narrowest catamaran configuration. After the verification procedure, the obtained results utilizing fine mesh are validated against available experimental data from literature (Souto-Iglesias et al., 2012). After verification and validation procedure for the free surface simulations, the double body simulations are performed. These simulations are carried out utilizing grid that has comparable density to fine mesh used in free surface simulations. The obtained numerical results are used to gain better insight into interference phenomena and the flow between demihulls.

2. Governing equations

In numerical simulations of incompressible viscous flow, RANSE along with averaged continuity equation are used as governing equations. RANSE and averaged continuity equation are obtained by time averaging of Navier-Stokes equations and continuity equation. RANSE and averaged continuity equation are given as follows (Ferziger and Perić, 2012):

$$\frac{\partial(\rho\overline{u}_i)}{\partial t}+\frac{\partial}{\partial x_j}\left(\rho\overline{u}_i\overline{u}_j+\rho\overline{u'_iu'_j}\right)=-\frac{\partial\overline{p}}{\partial x_i}+\frac{\partial\overline{\tau}_{ij}}{\partial x_j} \tag{1}$$

$$\frac{\partial(\rho\overline{u}_i)}{\partial x_i}=0 \tag{2}$$

where ρ is the fluid density, $\overline{u}_i$ is the averaged Cartesian components of the velocity vector, $\rho\overline{u'_iu'_j}$ is the Reynolds stress tensor and $\overline{p}$ is the mean pressure. The mean viscous stress tensor is defined with following equation:

$$\overline{\tau}_{ij}=\mu\left(\frac{\partial\overline{u}_i}{\partial x_j}+\frac{\partial\overline{u}_j}{\partial x_i}\right) \tag{3}$$

where μ is the dynamic viscosity.

Equations (1) and (2) represent unclosed set of equations. In order to close this set, turbulence model is introduced. Eddy-viscosity model for the Reynolds stress tensor is based on a fact that effect of the turbulence