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Numerical Simulation on Wave Interference of Catamaran with Fin Stabilizer

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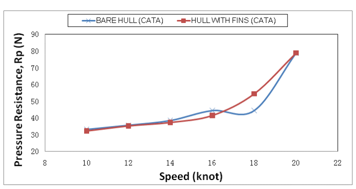
Graphical abstract



Abstract

Generated wave pattern of twin hull ship is important in analyzing wave interference between hulls. As each hull will generate own wave pattern, which might be identical for both hulls, the interference of wave generated can be either amplification or reduction factor for wave making resistance of the twin hull ship. Free Surface Flow is important to be considered in wave making resistance analysis of twin hull including hull with fin stabilizer, especially for ship operates in shallow water condition. Computational analysis using Computational Fluid Dynamics (CFD) simulation is performed using Reynolds Average Navier-Stokes (RANS) to solve free surface effect problem. The method which applied is Volume of Fluid method, considering two phase condition. The objective of simulation is to predict the wave making resistance and flow pattern of catamaran with and without fin stabilizer, considering the relationship between wave interference and fins stabilizer. The analysis is performed in two configurations, bare hulls and hulls attached with fins. For both configurations, the investigation was conducted with range of model speed from 10 to 20 knots using k-epsilon turbulence model in shallow water condition. The results were based on pressure resistance (Rp) and flow pattern around hulls.

Keywords: Wave making resistance; fins stabilizers; CFX simulation; catamaran; free surface effect; wave interference effect

1.0 INTRODUCTION

1.1 Background

One of the main issues regarding twin hull ship operated in shallow water is wake wash. The decay of the generated wave perpendicular to the ship's course is important from a coastal engineering point of view. When the waves enter shallow water, the wavelength decreases and the wave amplitude increase, resulting in the bank effect and also erosion problem. [1] In the other hand, it is a need to investigate ways to reduce the large resistance occurrence in order to minimize the required propulsive power and fuel consumption.

In recent years, optimization of ship fin stabilizer is getting more popular but it focuses on seakeeping and maneuvering aspect of vessel. Hull with fins differs from conventional hull based on way of generating lift; hull with fins obtains lift by hydrodynamic factor while conventional hull obtains by hydrostatic buoyancy. As fin stabilizers affect the hull form of the catamaran and consequently affect the profile of wave generated, it can be said that the fin stabilizes will give effects to the wave making resistance of catamaran and wash generated by the ship. [2]

The simulation is performed to analyze effect of wave interference on catamaran flow pattern and wave making resistance with existence of fins stabilizer and consideration of free surface flow. The numerical study was performed by CFX ANSYS software. Free Surface Flow is important to be considered in wave making resistance analysis of twin hull including hull with fin stabilizer, especially for ship operates in shallow water condition. Computational analysis using Computational Fluid Dynamics (CFD) simulation is performed using Reynolds Average Navier-Stokes (RANS) to solve free surface effect problem. The method which applied is Volume of Fluid method, considering two phase condition. [3]

1.2 Wave Interference Effect

A detail explanation about interference wave resistance between two or more hulls is obtained from Ref [4]. Yeung [4] referred theory of Michell for wave-making resistance of monohull and numerical method by Yeung for free surface flows. He stated the wave-making resistance, Rw of the two hulls with finite separation and stagger is given by Equation (1).

$$\begin{aligned} Rw_T &= Rw_1 + Rw_2 + Rw_{1\leftrightarrow 2} \\ &\equiv Rw_1 + Rw_2 + Rw_{1\rightarrow 2} + Rw_{1\leftarrow 2} \end{aligned} \quad (1)$$

The interference resistance, denoted by $Rw1\leftrightarrow 2$, equal to sum of the effect of Hull 2 on Hull 1 ($Rw1\leftarrow 2$) and the effect of

Hull 1 on Hull 2 (Rw1→2). Double hull vessel affect the wave-making resistance as each hull produce wave and the interference of the wave will give cancellation and amplification effect of the wave. Conclusion from analysis [2] [4] have proved one method in order to reduce wave effect from ship movement is by applying wave interference effect. Analytically, these effects can be expressed as

$$Rw_{1\leftrightarrow 2} = Rw_{1\leftarrow 2} + Rw_{1\rightarrow 2} \quad (2)$$
$$= \frac{\rho u^2}{\pi} \iint_{S1} dx_1 dz_1 f_1 x_1 \iint_{S2} d\xi_2 d\zeta_2 f_2 \xi_2 \times Gx_2(x_1 - \xi_{2;} sp; z_{1,} \zeta_2)$$
$$+ \frac{\rho u^2}{\pi} \iint_{S2} dx_2 dz_2 f_2 x_2 \iint_{S1} d\xi_1 d\zeta_1 f_1 \xi_1 \times Gx_1(x_2 - \xi_{1;} sp; z_{2,} \zeta_1)$$

Another mechanism involved in wave interference effect is existence break away and backwash portion as explained in Ref [5]. Way to reduce wave making resistance by installing fin-like plates on hull is proposed. The viscosity of the fluid causes a velocity distribution due to wall surface friction. A break-away portion (a) is formed in the rear end and back wash portion (b) is formed in the space between the rear end and the hull as shown in Figure 1. This causes waves created by the progress of the ship been cancelled as the waves pass over the rear end of plate.

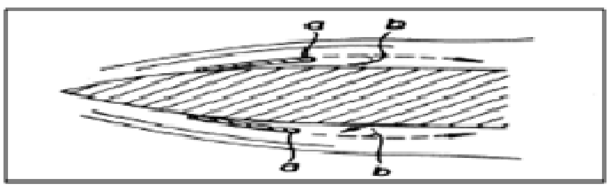


Figure 1 Break-away portion and back-away portion around hull with a pair of fin-like plates [5]

2.0 MATHEMATICAL FORMULATION

2.1 Governing Equation

The simulation in the present study used viscous flow solver, RANS code to apply free surface effect on the simulation with relevant effect on the development of longitudinal vortices and on the viscous component of drag. The Navier-Stokes equations are the basic governing equations for a viscous, compressible real fluid. It is a vector equation obtained by applying Newton's Law of Motion, so called as momentum equation with implementation of continuity equation. The equation can be written as:

$$\rho\left[\frac{du}{dt} + u \cdot \nabla u\right] = -\nabla p + \mu \nabla^2 u + f \quad (3)$$

Volume of Fluid (VOF) method is applied to assess free surface fluid motion in the simulation. VOF determines the shape and location of free surface based on the concept of a fractional volume of fluid Eulerian fixed-grid technique, where flow is inviscid and μ in Navier Stoke equation is equal to 0. The governing equation of this method is initiated by Euler equation:

$$\rho\left[\frac{D\vec{V}}{Dt} + u \cdot \nabla u\right] = \rho \vec{g} - \nabla p \quad (4)$$

The evolution of VOF function in Equation (5) is expanded from Equation (4) and continued by using condition DF/Dt=0.

$$\frac{D\vec{F}}{Dt} = \frac{\partial F(\vec{x}, t)}{\partial t} + (\vec{V} \cdot \nabla) F(\vec{x}, t) = 0 \quad (5)$$

F = 0 corresponds to an empty element occupied by no fluid
F = 1 corresponds to a full element occupied by the fluid
0 < F < 1 if cell contains the interface between the fluids (free surface)

2.2 Turbulent Model

The simulation used k-epsilon (k-e) turbulence model to represent turbulence properties in the simulation with assumption that the pressure gradient is small. This two-equation model consists of transport equations which are solved for turbulent kinetic energy k and its dissipation rate ε. The basic transport equations are governed from time averaged Navier Stoke equation when continuity equation, Equation (6) is applied:

$$\frac{\partial u_i}{\partial x_i} = 0 \quad (6)$$

$$\frac{\partial \vec{u}_i}{\partial t_i} + \vec{u}_j \frac{\partial \vec{u}_i}{\partial x_j} = \vec{f}_i - \frac{1}{\rho}\frac{\partial \vec{p}}{\partial x_i} + \nu \frac{\partial^2 \vec{u}_i}{\partial x_j \partial x_j} - \frac{\partial \vec{u}_i \vec{u}_j}{\partial x_j} \quad (7)$$

The Reynolds stress is an extra terms in momentum equation and can be expressed as a tensor, as written in Equation (8). The modeled k epsilon equation, Equation (9) is governed after combining the derived tensor of Reynolds stress with energy dissipation, turbulent diffusion, and pressure fluctuation with the transient, convective, and viscous terms. The dissipation is given by Equation (10) and eddy viscosity is given by Equation (11) where C_D and C_μ is constant.

$$\tau_{ij} = -\overline{\rho u_i' u_j'} \quad (8)$$

$$\rho \frac{\partial k}{\partial t} + \rho \frac{\partial}{\partial x_j}\left(U_j k\right) = \tau_{ij} \frac{\partial U_i}{\partial x_j} - \rho \varepsilon + \frac{\partial}{\partial x_j}\left(\mu + \frac{\mu_t \partial k}{\sigma_t \partial x_j}\right) \quad (9)$$

$$\varepsilon = C_D \frac{k^{3/2}}{l} \quad (10)$$

$$\mu_t = C_\mu \rho k^{1/2} l \quad (11)$$

3.0 METHODOLOGY

3.1 Model of Catamaran and Fins

The model which is used in this study is catamaran with fixed fin at fore and adjustable fin at aft of the hull and the position of fin is shown in Figure 2. The particulars dimensions of the model are shown in Table 1 and the particulars for fins stabilizer is presented in Table 2.

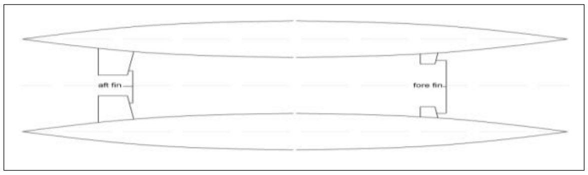


Figure 2 Position of fore fin and aft fin on hull

Table 1 Particular dimensions of Wigley Catamaran

Dimensions	Full Scale	Model
Length over All (m)	23.11	2.311
Breadth over All	8.0	0.8
Breadth Hull	1.6	0.16
Hull spacing between centerlines (m)	6.4	0.64
Draft at the midship (m)	2	0.2
h/D Ratio for Simulation	-	3.0

Table 2 Fins stabilizer particulars

Parameter	Full Scale		Model scale	
	Fore	Aft	Fore	Aft
Section Type	NACA 0015			
Scale	1		10	
Length of Span (m)	1.2	1.85	0.12	0.185
Length of Chord (m)	0.96	1.6	0.096	0.16
Position from C.G. (m)	7.0	9.24	0.7	0.924
Aspect Ratio	1.25	1.15	1.25	1.15

3.2 Computational Grid and Domain

Computational grid is a important matters to consider in performing CFD validation to ensure the accuracy for result. In order to make the simulation faster, the computational grid have to provide small number of panel. In many cases based on catamaran cases, the grid considered is just for one side hull is discretized and the grid is symmetry about plane y=0 for twin hull. This is applied in producing mesh in CFX for Catamaran hull and NACA 0015 fins stabilizer.

3.3 CFX Numerical Simulation

CFX is one of software capable in calculating ship resistance. For this simulation, steady state simulation is applied with k-epsilon turbulence model. The boundary condition involved:

i. Inlet
ii. Outlet
iii. Symmetry Plane
iv. Wall (No-Slip)
v. Wall (Free-Slip)
vi. Interface

In generating mesh for computational domain of this work, the mesh is divided into structured and unstructured mesh. Structured mesh is produced around region between the top and bottom of hull to increase effect of water flow. Interface boundary condition is set to connect the region between structured and unstructured mesh as shown in Figure 3. The size of the mesh at the region closer to hull and fin is set to be four time smaller than the other region.

The size of computational domain is referred to Zaghi [6] in his work of simulation on catamaran wave resistance as shown in Figure 4. The physical parameters and solver settings used to define the numerical solution are provided in Table 3. The time convergence in CFX simulation is shown in Figure 5.

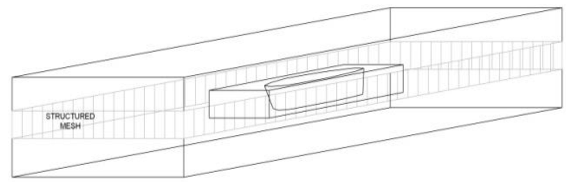


Figure 3 The view of structured and unstructured mesh connected by interface

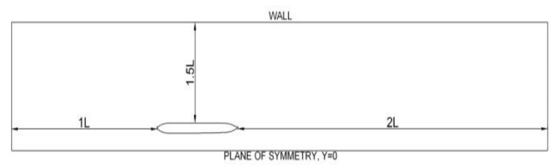


Figure 4 The computational domain for catamaran simulation adapting domain from Ref. [6]

Table 3 Physical parameters for simulation

Parameter	Properties
Type of mesh	Unstructured (Tetra/Mixed Volume mesh), Structured (Prism)
Domain Physics	Homogeneous Water/Air multiphase, Automatic wall function, Buoyancy model–density difference, Standard free surface model
Boundary physics:	
Inlet	Inlet with defined volume fraction, flow speed from 5.144 m/s, turbulence intensity 0.05
Outlet	Opening with entrainment with relative pressure = downstream pressure
Bottom/side wall/Top	Wall with free slip condition
Hull	Wall with no slip condition
Symmetry plane	Along centreline of the hull
Solver settings:	
Turbulence Numeric	Fist Order
Advection scheme	High Resolution (ANSYS, 2009)
Timescale control	Physical timescale function: 0.02[s]
Convergence criteria	Residuary type: RMS, Target: 0.001
Multiphase control	Volume fraction coupling

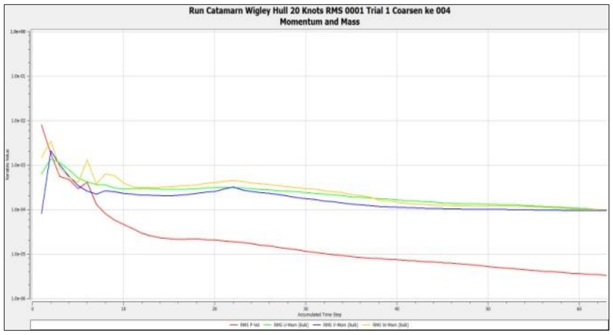


Figure 5 Graph of time convergence CFX simulation for Wigley Catamaran

■4.0 RESULT AND DISCUSSION

There are comparisons on the pressure resistance (Rp) which obtained from the simulation; with different speed from 10 to 20 knots as shown in Figure 6. The wash criteria are analyzed according to the wave profile presented by the wave amplitude contour. Note that in this simulation, the pressure resistance value indicates summation of wave making resistance (Rw) and viscous pressure resistance (Rvp). Assuming the Rvp is not dominant in this case, Rp value can be referred to analyse Rw.

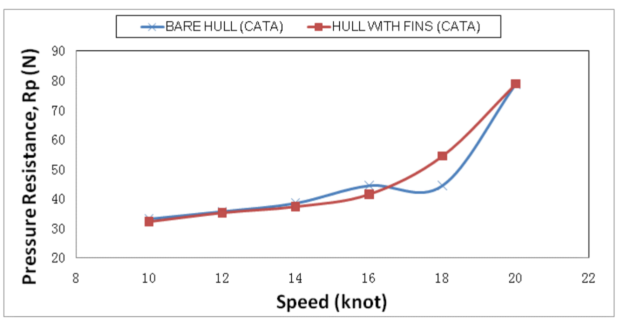


Figure 6 Pressure Resistance Curve for Catamaran Bare Hull and Hull with Fins

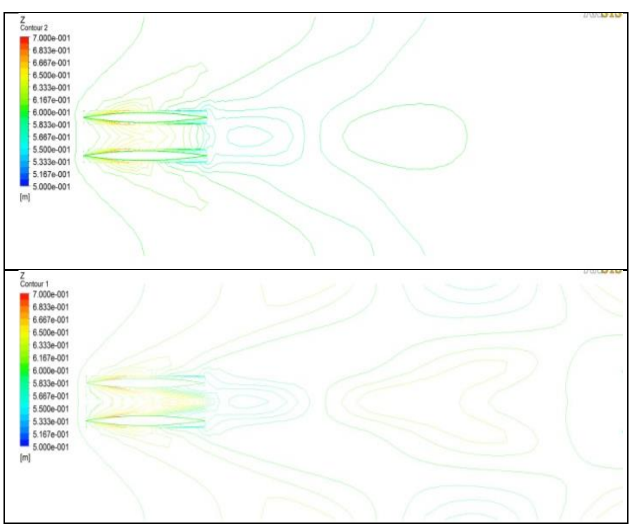


Figure 7 Comparison between Wave Profile of Catamaran Bare Hulls (above) and Hulls with Fins (below) at 10 knot

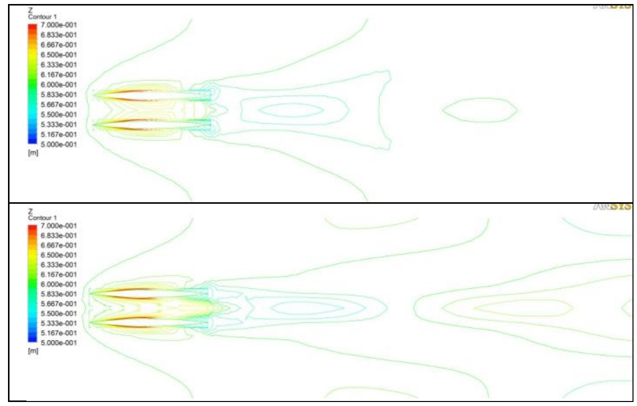


Figure 8 Comparison between Wave Profile of Catamaran Bare Hulls (above) and Hulls with Fins (below) at 14 knot

For the comparison of pressure resistance between bare hulls and hulls with fins, the result shows that there is decreasing effect by the fins on wave generated resistance during the movement of ship. However, the effect is not present at all speed. As shown in Figure 4, fins stabilizer installation has reduced the Rp value from 10 to 16 knot. After that, Rp value for hulls with fins exceeding the Rp value of bare hulls. The effect of fins is not critical at speed 20 knot as Rp value for both cases is slightly similar. This shows that the fin installation gives effect to pressure distribution along hulls and forms its own wave system.

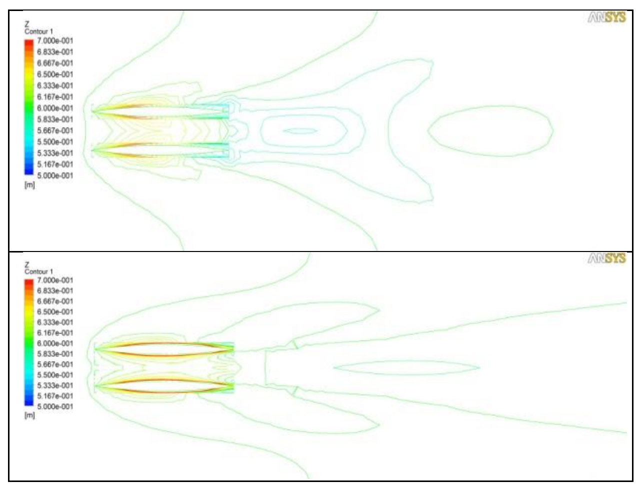


Figure 9 Comparison between Wave Profile of Catamaran Bare Hulls (above) and Hulls with Fins (below) at 20 knot

The movement of ship which assisted with stabilizer produces cancelling wave effect regarding to wave interference at low speed. The occurrence of break away and backwash portion contribute to this effect as explained previously. However, as the speed become higher, the cancelling wave effect does not exist.

For the wash performance of the ship, the wave amplitude contour in Figure 7 to 9 indicates the wash energy generated from catamaran from bow to stern part of hull as well as wake behind the catamaran at different speed. At 10 knot, pattern of generated wave shown in Figure 7 is similar for both cases but for hull with fins case, the wave amplitude is higher at far field. At area near wall, there is occurrence of trough wave. This is very similar with effect of fin at 14 knots and 20 knots as shown in Figure 8.

However, at 20 knots, the wave amplitude shown in Figure 9 is slightly reduced at area near hull.

The comparison between bare hulls and hulls with fin shows that the energy of wave affected by wave induced by fin resulting in higher wash. The wave generated around hull for the case of hulls with fins experience wave crest at far field and also area behind hull at most of the speed. This phenomenon shows the wave interference between hulls and fins stabilizer give varying effect on the pressure resistance and energy of wave generated. However, the increasing of wave amplitude affected by fins is more dominant.

■5.0 CONCLUSION

The simulation on the Catamaran resistance performance in shallow water has been done to achieve the objective. From the simulation, the effects of fins towards catamaran wave making resistance and wake wash performance are obtained. The installation of fins reduces the wave making resistance value of the vessel at different range of speed. However, fin stabilizer affects increase on wave amplitude at most of operation speed. This shows that wave interference between wave of hull and wave of fin create amplification factor.

Further research for this Catamaran design will be carried out in order to investigate more on the wave interference phenomena of the vessel. That includes the optimum angle of attack of the fins to minimize the amplification of wave making resistance and wake wash generated by fins wave. The unsteady case should be involved to investigate the change of wave performance with time.

Acknowledgement

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