EFFECTS OF FIN STABILIZER CONFIGURATIONS ON SEMI SWATH RESISTANCE

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Bismillahirrahmanirrahim

To my beloved parents, my caring husband, my angles Amna Safiyya and Amna Afiyah and my precious Abdul Rahman.

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ABSTRACT

The installation of the fin stabilizers on the Semi Small Waterplane Area Twin Hulls (Semi SWATH) vessel reduces the disadvantages of its low restoring force. The important role of the fins in increasing the lift force on Semi SWATH brings the need for the hydrodynamic assessment, including the effect of fins on the Semi SWATH resistance. In this thesis, the resistance and wake wash of the Semi SWATH model with separation over length ratio, 0.35 and 0.30 were investigated. The investigation considers the fin stabilizers' configurations, which change the induced drag and lift and flow pattern around the hulls. Numerical simulation was carried out to examine the mentioned criteria using the ANSYS CFX software with build in Reynolds Average Navier-Stokes (RANS) code in deep and shallow water conditions. Validation of the numerical result was based on the experimental result, which was performed in towing tank at the Universiti Teknologi Malaysia. It was discovered that the computational result showed up to 11% maximum average error. This error is larger as compared with other catamaran computational cases, which is mainly caused by the limitation of the computational tools in producing good computational grid and simulating the turbulence free surface flow in the complex hull form. It was concluded that the fins' installation angle changes the pressure distribution and wave propagation around the hulls, which increases the total resistance up to 70.9% in deep water and 40.3% in shallow water by average. The resistance increment from shallow water effect for the hulls with 15º fin angle showed 56.5% reduction compared to the bare hulls case. An extended parametric study in shallow water concluded that the total resistance enlargement can be avoided by 27.7% from the appropriate hull and fin parameters, including smaller water depth, larger hull separation distance and small angle of fore fin stabilizers. The findings of the research can be a guideline for the modification of the fin stabilizer configurations for the catamaran and the extending application of Semi SWATH in shallow water region.

ABSTRAK

Pemasangan sirip penstabil pada kapal Semi SWATH mengurangkan kelemahan dari aspek kuasa balikan yang rendah. Fungsi penting sirip penstabil dalam meningkatkan daya angkat Semi SWATH menyebabkan perlunya penilaian hidrodinamik termasuk kesan sirip terhadap rintangan kapal. Dalam tesis ini, rintangan dan corak aliran ombak pada model kapal Semi SWATH dengan nisbah jarak pemisah per panjang, 0.35 dan 0.30 telah dikaji. Kajian mengambilkira konfigurasi sirip penstabil yang mengubah daya seret dan daya angkat serta corak aliran bendalir di sekeliling badan kapal. Simulasi berangka telah dijalankan untuk menilai kriteria yang disebutkan menggunakan perisian ANSYS CFX dengan kod Reynolds Average Navier-Stokes (RANS) pada kondisi air dalam dan air cetek. Validasi bagi dapatan berangka adalah berdasarkan dapatan eksperimen yang diperoleh daripada ujian rintangan di tangki tunda yang berada di Universiti Teknologi Malaysia. Maksimum ralat purata yang dihasilkan daripada kaedah berangka adalah sebanyak 11%. Faktor utama nilai ralat yang lebih besar berbanding analisa berangka katamaran yang lain adalah limitasi kaedah berangka dalam penghasilan grid simulasi dan simulasi aliran turbulen pada permukaan air bagi kapal berekabentuk kompleks. Secara konklusi, sudut pemasangan sirip mengubah distribusi tekanan dan propagasi ombak di sekitar badan kapal dan meningkatkan rintangan total sehingga 70.9% pada kondisi air dalam dan 40.3% pada air cetek secara purata. Peningkatan rintangan yang disebabkan kesan kedalaman air yang terhad bagi kapal dengan sudut sirip 15º berkurang sebanyak 56.5% berbanding kes kapal tanpa sirip. Kajian parametrik lanjutan pada kondisi air cetek merumuskan sebanyak 27.7% peningkatan rintangan keseluruhan dapat dielakkan berdasarkan modifikasi sirip dan badan kapal yang sesuai termasuk mengurangkan kedalaman air, meningkatkan jarak pemisah badan kapal, dan mengurangkan sudut sirip penstabil hadapan. Hasil kajian ini boleh menjadi panduan dalam mengubah konfigurasi sirip penstabil bagi katamaran dan meluaskan operasi Semi SWATH di kawasan air cetek.

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LIST OF ABBREVIATIONS

Vessel/ Environment Parameters

η	-	Breadth of a ship
ρ	-	Density of water
Fr_H	-	Depth Froude Number
T	-	Draught of ship
EHP	-	Effective horse power
U	-	Flow Velocity
Fr	-	Froude Number
g	-	Gravitational acceleration
Fr	-	Length Froude Number
L	-	Length of ship
GM_L	-	Longitudinal metacentric height
E	-	Propulsion efficiency
Re	-	Reynold Number of water
s	-	Separation distance between hull
C_b	-	Ship block coefficient
SWATH	-	Small Water Plane Area Twin Hulls
V	-	Vessel Speed
V	-	Volume displacement
h	-	Water depth
v	-	Water kinematic velocity
μ	-	Water viscosity
λ	-	Wavelength
S	-	Wetted surface area

Fin Stabilizer

α	-	Angle of attack
R_{AP}	-	Appendage resistance
S_{AP}	-	Appendage wetted surface area
c	-	Chord length

C_D	-	Drag coefficient
EFS	-	Effect of fin stabilizer
C_L	-	Lift coefficient
A	-	Projected fin area

Forces and Moments

R_{AP}	-	Appendage resistance
Cf	-	Coefficient of friction resistance
ϕ	-	Coefficient of pressure field change around the demi-hull
Cp	-	Coefficient of pressure resistance
Cr	-	Coefficient of residual resistance
Cf_o	-	Coefficient of skin friction resistance
Ct	-	Coefficient of total resistance
σ	-	Coefficient of velocity augmentation between the hulls
C_W	-	Coefficient of wave resistance
D	-	Drag force
$1+k$	-	Form factor
Rf	-	Friction resistance
IF	-	Interference factor
L	-	Lift force
Rf	-	Pressure resistance
Δd	-	Sinkage
R_T	-	Total resistance
R_{TWF}	-	Total resistance with fin
R_{TWOF}	-	Total resistance without fin stabilizer
θ_t	-	Trim angle
M_Y	-	Trim moment
R_Z	-	Vertical hydrodynamic force
β	-	Viscous resistance interference coefficient
R_W	-	Wave resistance
τ	-	Wave resistance interference coefficient

Coordinate System

OXYZ	-	Fixed coordinate system
OsXsYsZs	-	Moving coordinate system

Governing Equation / Hydrodynamic Coefficient

f_i	-	Acceleration due to volumetric force
A_{jk}	-	Added mass coefficient
F_4, F_5 and F_6	-	Amplitudes of the roll, pitch, and yaw exciting moment
F_1, F_2 and F_3	-	Amplitudes of the surge, sway, and heave exciting forces
F_{jk}	-	Complex amplitudes of the exciting force and moment
M_{jk}	-	Components of the generalized mass matrix of the ship
B_{jk}	-	Damping coefficient
C_{jk}	-	Hydrostatic restoring coefficient
θ	-	Momentum thickness,
p_x, p_y, p_z	-	Partial derivatives of pressure component
u_x, u_y, u_z, v_y, v_z, w_z, u_t, v_t, w_t	-	Partial derivatives of velocity component
φ	-	Velocity potential

Experiments and Simulation

h/T	-	Depth to draught ratio
y	-	Distance from sailing line
y^+	-	Y plus

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CHAPTER 1

INTRODUCTION

1.1 Background

In conjunction with the changing needs of marine transportation, many advanced multihull designs have been developed nowadays. The recent design includes semi displacement hull, where the vessel displacement operated at high speed is not fully supported by the submerged hull due to the buoyancy reduction. A ship within this category, which is preferred as the marine transportation modes is the catamaran type.

In the early 19th century, catamarans were widely used in the transportation system due to its large deck area. One of the highlights of their performance was low resistance and good stability in the high-speed conditions. Furthermore, their hull designs, which promote large dynamic motion with increasing ship speed, especially while running in the head seas condition are critical. The early development of high-speed catamarans was focused on the passenger ferries. However, in recent years, catamarans are widely used as the multipurpose marine transportations including public transportation, industrial, military and commercials.

The modern type catamaran such as Small Waterplane Area of Twin Hull (SWATH) possesses different features compared to the conventional ones. A SWATH designed by Frederick G. Creed, which was developed in a multihull with the torpedo-like underwater structure supporting the hull displacement was used for cruising and transportation purposes (Smith, 1982). Routa (1985) and Lang (1988) also reported the SWATH applications for cruising, canal and harbour operations as well as the oceanography research vessel.

From the design point of view, the small waterplane area of a SWATH ensures low wave response to the hull, which is important in evaluating the vessel seakeeping performance in all conditions. The small waterplane area ships can achieve similar seakeeping state as a monohull with 5-15 times larger displacement and twice the speed as compared to the previous seakeeping state *(*Dubrovsky, 2010). However, such criterion comes with a few drawbacks such as large resistance and power consumption caused by the large wetted surface area of the hull and difficulty in designing the machinery and propulsion system due to narrow space of the underwater structure (Medaković *et al.,* 2013). Another drawback, which can affect the quality of the design is the large trim effect whereby the ship is exposed to larger forces.

A hybrid design, which combines SWATH design in the fore and catamaran in the aft or known as Semi SWATH can become an alternative design. The design was generated after laborious research on the performance assessment of the SWATH and catamaran hull forms. The best approach in combining both hull designs was sought with the intention to subdue their weaknesses while giving emphasis to their operating power and motion responses. Among the disadvantages of the original designs include seakeeping problem in rough seas, speed loss at high speeds and high cruising power.

The first hybrid design was suggested by Shack (1995) after reviewing the unsolved problems of a fast passenger vessel, including resistance, seakeeping, propulsion and comfortability. The Semi SWATH design was described for Seajet vessel, which adapts the high speed of catamaran and the optimal seakeeping of SWATH based on the minimum vessel stiff response to promote passengers' comfort. A few years later, Holloway (2003) presented the benefits of combining both the catamaran and SWATH designs whereby the most highlighted one is a smooth ride in the various wave conditions and speeds.

The need of having an environmentally friendly coastal and inland waterways transportation such as passenger ferries has brought to the discussion towards the extended application of Semi SWATH, following previous use of catamaran and SWATH based on its smooth ride performance in the wavy open sea. The earlier study performed by Mat (2007) discussed the adaptability of Semi SWATH as the coastal passenger ferry. The proposed general arrangement is depicted in Figure 1.1. The finding discovered by Jupp *et al.* (2014) supports the extending application of Semi SWATH at the High Speed Craft (HSC) in the coastal region and inland waterways. The finding shows that the design of Semi SWATH ranked second and third for the vessel type criteria in term of technical and commercial respectively. However, more research should be done to investigate the feasibility of such HSC in the coastal regions and inland waterways, especially due to the wake wash problem. These issues have encouraged engineers to perform deeper analysis on the crucial part of the vessel performance namely dynamic motion and hydrodynamic analysis.

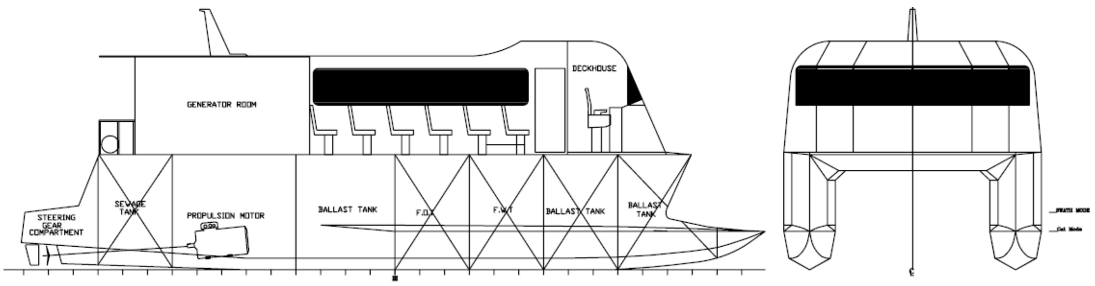

Figure 1.1: General arrangement of the Semi SWATH as the coastal passenger ferry (Mat, 2007)

The dynamic motion analysis results from the Semi SWATH critically unstable motion due to the pitching moment, especially at the high-speed conditions. As such, a stabilizing system using the fin stabilizers is applicable to reduce the large pitching moment while at the same time increase the stability of the vessel against the moments generated by roll and yaw motions. However, Faltinsen (2006) emphasized the relationship between foil and ship resistance, lift and cavitation reduction. Therefore, the fin design and configuration should be analysed accordingly to ensure the effectiveness of producing appropriate moments to stabilize the vessel and acceptable resistance properties in the various conditions. As for the hydrodynamic analysis, more attention is given to calm water and shallow water analysis, which is important to ensure Semi SWATH can be operated in various operating conditions. From the point of view of coastal and inland waterways operations (shallow water conditions), the focus is mainly on wake wash as it leads to bank effect and erosion.

1.2 Problem Statement

Discussion on the feasibility of Semi SWATH for coastal and inland waterways operations involves shallow water and calm water operating conditions where the effect of sea wave condition to the hull resistance is not affected much (Molland *et al.*, 2008). The less available resources on the resistance properties of Semi SWATH compared to the seakeeping properties have been addressed by Vernengo *et al.* (2014). Hence, resistance analysis of Semi SWATH in both conditions is essential in the Semi SWATH design development.

Based on the Semi SWATH operating performance, there is a need to study the effectiveness of its stabilising system in achieving the optimal hydrodynamic performance of multihull. The important hydrodynamic criteria for the proposed application of Semi SWATH in open sea, coastal region and inland waterways include resistance and wake wash. The previous research on Semi SWATH seakeeping as performed by Rahimuddin (2013) highlighted the importance of fin stabilizers to improve the lift force and damping force. The drag and lift effect from the fin stabilizer configuration including fin angle on the Semi SWATH resistance should be further analysed as varied characteristics from different fin angles influence the Semi SWATH resistance due to the difference in generated interference resistance and flow velocity around hulls. Furthermore, the stabilizing system tends to produce enlargement or reduction factor to the hull resistance, which depends on the factor of design and particular.

The contributing factors to the resistance and wake wash of the Semi SWATH with fin stabilizers should be analysed, including the impact of generated wave, interference factor and existence of the appendages. The pressure distribution and generated wave pattern analysis should be performed to determine the effect of fin stabilizers on the Semi SWATH resistance components. Accordingly, different appendages configuration effect should be investigated to discover the in-depth relationship between the fin stabilizers and the Semi SWATH resistance.

This research focuses on the configuration of the installed fin stabilizers on Semi SWATH, which converged to the relationship between the anti-pitch fins configuration on Semi SWATH and the hull hydrodynamic factors, including hull trim condition and generated wave around the hulls. The research offers significant contribution as there is a minor discussion on the mentioned topic compared with seakeeping improvement. The finding of the research is useful to discuss the improvement factor of the available fin stabilizers design while the relationship is treated as the guideline for varying fins configurations methods according to fins and multihull effectiveness.

1.3 Research Questions

The research was conducted based on the following research questions:

1. What is the contributing factors of the Semi SWATH resistance with fin stabilizer?
2. How do the Semi SWATH hulls and fins configuration affect the hull resistance components?
3. What is the fin stabilizers configurations effect on the Semi SWATH resistance and wake wash in deep water and shallow water conditions?

1.4 Research Objectives

The study aimed at analysing the Semi SWATH performance, which considers the configuration of the fin stabilizers attached to the twin hulls. The objectives of the research were outlined as follows:

1. To determine the contributing factors of the Semi SWATH resistance with fin stabilizers.
2. To examine the relationship between the configurations of fins and the Semi SWATH resistance components.
3. To evaluate the effect of fin stabilizers configurations on the Semi SWATH resistance and wake wash in deep water and shallow water conditions.
4. To assess the parameters of hull and fin stabilizer of Semi SWATH in shallow water resistance aspect.

1.5 Research Scope

The research is focused on two main components: fin stabilizers configuration based on its effectiveness and Semi SWATH performance in resistance. The important aspect to be considered is the influence of fin stabilizer in producing approximate lift and smooth flow at the same time maintaining good seakeeping and resistance criteria. The scope of the research was outlined as follows:

1. Vessel performance is commonly divided into calm water analysis and seakeeping response. As the seakeeping response of similar Semi SWATH has been covered in previous work, the current research focused on calm water analysis.
2. The analysis was performed in deep water for the analysis of Semi SWATH at the designed speed condition and shallow water for analysis at Depth Froude number.
3. The methods comprised the computational method using Computational Fluid Dynamic to simulate the problem and the experimental method to validate the simulation results.
4. The main analysis focused on the resistance of the Semi SWATH with and without fin stabilizer at the designed speed and shallow water condition. Further details on the effects of fin stabilizers configurations on the Semi SWATH resistance components and hull generated waves are given by

analysing the effects of changing the aft fin angle, which considers the interference resistance and non-dimensional ratio of the fin stabilizers.

5. The further parametric study, which involved the fin stabilizers configurations such as fin distance from seabed, fins installation angle and fins separation distance was performed in shallow water due to the critical effect of hull generated wave in this condition.

1.6 Thesis Outline

The research has been constructed in the most appropriate flow and procedure to study the effects of the fin stabilizers configuration on the resistance of the Semi SWATH.

Chapter 1 described background, objectives and scopes of the research.

Chapter 2 summarized reviews on the performance of the Semi SWATH and multihull characteristics, including resistance in the deep and shallow water. Reviews on the advanced marine vehicles, fin stabilizer characteristics, a method of hydrodynamic analysis and effect of appendages to resistance were elaborated as well.

Chapter 3 justified the method chosen for the research work to achieve the research objectives. The main approaches used were the computational fluid dynamic simulation where validation was performed by the resistance test. Further work on the parametric study was described in the chapter. This chapter explained the basic theory and mathematical formulation for the approach used in the research, especially the force distribution of total hull resistance and the derived equation of computational model for fluid dynamic simulation. The chapter also described the mathematical equation behind the measurement of hull resistance, wave amplitude and hull motion during the experiment.

Chapter 4 described the computational fluid dynamic simulation modelling method in the ANSYS CFX software based on the developed mathematical model as well as the measurement of wave amplitude by wave probe and the prediction of hull heave and trim angle. Accordingly, validation method for the simulation model developed was discussed, including the resistance test in deep and shallow water.

Chapter 5 presented the result of resistance components of the Semi SWATH bare hulls and hulls with changing aft fins angle in deep water at the designed speed. The results comprised the simulation results and experiment data, including the resistance and wave profile of the hulls at corresponding speed and the draft.

Chapter 6 elaborated comparison between the resistance components of Semi SWATH in deep and shallow water conditions based on different aft fin angles. The results include simulation results and experiment data of the resistance and wave profile as well as trim and sinkage of the hulls at the corresponding speed and draft. The parametric study results were further exposed in the total resistance obtained via simulation of the total resistance in shallow water condition based on the selected varying parameters namely water depth, hulls separation distance and fin angle at fore and aft of the hull

Chapter 7 finally concluded the current research and the recommendation of future works.

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