# SEAKEEPING PERFORMANCE OF SEMI-SWATH IN FOLLOWING SEA USING CONTROLLED FINS STABILIZER

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## ABSTRACT

Semi-SWATH ship design is a result of combining the good features of SWATH and Catamaran designs. However, the disadvantage of semi-SWATH is that she has low restoring force at bow that causes a tendency to bow-dive when running in following seas. In some critical conditions, the foredeck was found to be immersed underwater. One of the efforts to improve the ship's performance is to install fin stabilizers at bow and stern. The fin stabilizers are used to compensate for the low restoring force at the bow by increasing the lift force and damping force. A fuzzy logic controller developed for the system gives the ability to transform human knowledge and experience into the controller system and also to regulate the fin angle. A numerical simulation program developed in time domain for surge, heave, and pitch motions are then validated by seakeeping tests in towing tank of Marine Technology Centre, Universiti Teknologi Malaysia. Using the simulation program, parametric study was conducted to relate the ship and wave parameters with the ship's performance characteristics. The ship with fixed fin stabilizers has the bow-dive and immersed foredeck conditions at the following situations: for wave height to length ratio, Hw/Lw = 0.07, the wave to ship length ratio is $1.1 \leq Lw/Ls < 1.4$, and for Hw/Lw = 0.08, the wave to ship length ratio is $1.0 \leq Lw/Ls < 1.7$. For ship with active fin stabilizers, at Hw/Lw = 0.08 and $Lw/Ls > 1.6$, it was found that the foredeck was immersed with low surfing speed. Meanwhile, for the ship with fixed fin at bow and active fin at the stern, it was found that bow-diving and immersed foredeck did not occur.

# ABSTRAK

Rekabentuk kapal separa-SWATH adalah gabungan rekabentuk antara SWATH dan Katamaran. Walau bagaimanapun, kelemahan kapal separa-SWATH adalah ia mempunyai kuasa balikan yang rendah pada haluannya. Keadaan ini menyebabkan kapal tesebut cenderung mengalami keadaan haluan-menyelam ketika belayar di laut. Bahkan, dalam beberapa keadaan, geladak haluan didapati tenggelam. Salah satu usaha yang dibangunkan untuk meningkatkan prestasi kapal adalah penggunaan penstabil sirip di haluan dan di buritan. Sirip penstabil digunakan untuk mengimbangi kuasa balikkan yang rendah dengan meningkatkan kuasa angkat dan kuasa redam. Sebuah pengawal logik kabur telah dibangunkan dalam sistem kerana pengawal ini mempunyai keupayaan untuk menerapkan pengetahuan dan pengalaman manusia ke dalam sistem kawalan untuk mengawal sudut sirip. Sebuah program simulasi berangka dibangunkan dalam domain masa untuk gerakan terjah, lambung, dan rewang dan disahkan melalui ujian dalam tangki tunda di Pusat Teknologi Marin, Universiti Teknologi Malaysia. Dengan menggunakan program simulasi, kajian parametrik dilakukan untuk menghubungkan parameter kapal dan gelombang dengan ciri prestasi kapal. Kapal menggunakan semua penstabil sirip tetap mempunyai keadaan haluan-menyelam dan geladak haluan menyelam pada keadaan berikut; pada nisbah ketinggian ombak terhadap panjang ombak, $Hw/Lw = 0.07$ dan nisbah panjang gelombang terhadap panjang kapal, $1.1 \leq Lw/Ls < 1.4$ dan pada nisbah $Hw/Lw = 0.08$ dan nisbah $1.0 \leq Lw/Ls < 1.7$. Untuk kapal dengan semua penstabil sirip aktif pula, pada nisbah ketinggian ombak $Hw/Lw = 0.08$ dan nisbah $Lw/Ls > 1.6$, didapati geladak haluan tenggelam pada kelajuan luncur rendah. Sementara itu, bagi kapal dengan sirip tetap di haluan dan sirip aktif di buritan, didapati keadaan haluan-menyelam dan geladak haluan tenggelam tidak berlaku.

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## LIST OF SYMBOLS

| | | |
|---|---|---|
| L | - | Length of ship |
| B | - | Breadth of ship |
| Bh | - | Breadth of between ship |
| H | - | High speed |
| T | - | Draught of vessel |
| $K_G$ | - | Vertical height of centre of gravity from the Keel |
| GM | - | Metacentric height |
| GZ | - | Righting lever |
| Vs | - | Forward speed of vessel |
| $\Delta$ | - | Displacement |
| m | - | Mass of ship |
| $\ddot{s}_k, \dot{s}_k, s_k$ | - | Ship motion on *k* direction |
| $M_{jk}$ | - | Mass matrices, index *j* and *k* indicates the mode of motions and excitation |
| $A_{jk}, a_{jk}, I_{jk}$ | - | Added mass/Inertia matrices, element mass and inertial mass moment matrices, index *j* and *k* indicates the mode of motions and excitation |
| $B_{jk}, b_{jk}$ | - | Damping matrices, index *j* and *k* indicates the mode of motions and excitation |
| $C_{jk}, c_{jk}$ | - | Restoring matrices, index *j* and *k* indicates the mode of motions and excitation |
| $F_k$ | - | Force and moment vectors, index *k* indicates the mode of excitation |
| $\zeta_j$ | - | Displacement vectors, index *j* indicates the mode of motion |
| *T* | - | Propeller Thrust |

| | | |
|---|---|---|
| $R$ | - | Ship Resistance |
| $D_P$ | - | Propeller diameter |
| $K_T$ | - | Propeller thrust coefficient |
| $U$ | - | Propeller incoming water velocity |
| $U_o$ | - | Assigned as initial water velocity equal to *Vs* |
| $n_p$ | - | Number of propeller revolution |
| $w_p$ | - | Propeller wake |
| ρ | - | Mass water density |
| $S(x)$ | - | Sectional area at distance *x* |
| $x_o$ | - | Initial distance ship to wave |
| $x_s$ | - | Initial distance section |
| $k$ | - | Wave number |
| $F_j^f$ | - | Force or moment in *j* motion excited by fin stabilizer, *f*. |
| $F_j^w$ | - | Force or moment in *j* motion excited by wave, *w*. |
| $A_{wp}$ | - | Waterplane area |
| $x_G$ | - | Centre of gravity |
| *Vs* | - | Ship speed |
| $V_A$ | - | Advanced speed |
| **A** | - | Matrices state |
| **B** | - | Matrices input |
| **C** | - | Matrices output |
| **x** | - | Vector state |
| **y** | - | Vector output |
| **u** | - | Vector input |
| $C_R$ | - | Chords of root |
| $C_T$ | - | Chords of tip |
| $C_L$ | - | Lift coefficient |
| $C_D$ | - | Drag coefficient |
| $C_{D0}$ | - | Minimum drag coefficient |
| $S_P$ | - | Span / outreach |
| $\bar{c}$ | - | Mean of chords |
| $A_F$ | - | Projection of area |
| δ | - | Angle of fin by controller |

| | | |
|---|---|---|
| $l_f$ | - | Fin stabilizer distance to centre of rotation |
| $a_F$ | - | Aspect ratio |
| $m_f$ | - | Mass of fin |
| $E$ | - | Total effective fin |
| $E_{BL}$ | - | Effective fin by boundary layer effect |
| $E_{IF}$ | - | Effective fin by interference fin effect |
| $E_{FS}$ | - | Effective fin by fin submergence effect |
| $F_D$, $F_1^f$ | - | Drag force of fin |
| $F_L$, $F_2^f$ | - | Lift force of fin |
| $M_f$, $F_5^f$ | - | Moment of fin |
| $F_1^w$ | - | Drag force of fin |
| $F_2^w$ | - | Lift force of fin |
| $F_5^W$ | - | Moment of fin |
| u | - | Longitudinal orbital of the wave particles |
| υ | - | Vertical orbital of the wave particles |
| $a$ | - | Wave amplitude |
| $Vw$ | - | Wave celerity |
| Vw | - | Wave celerity |
| λw | - | Wave length |
| ζw | - | Wave profile |
| k | - | Wave number |
| η | - | Wave elevation |
| OXYZ | - | Fixed/earth coordinate system |
| OsXsYsZs | - | Ship coordinate system |
| T | - | Time response of first order model determined at 63.2% of maximum response |
| s | - | Operator of Laplace equation |
| $\delta_d$ | - | Desired fin angle input |
| δ | - | Fin angle response |

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# CHAPTER 1

# INTRODUCTION

## 1.1. Background

Research and development of high-speed ship in the world is developing. Particularly multihull ship, it began in 1700 when the Europe traders sail to the East Asia, and they found catamaran used before they recognize the multihull ship type. Catamaran design has two monohull ships connected together with bridge structure. Currently, Catamaran was famous fast ship with more stable, low draft, and high dynamic motion.

In the last of 20th century, SWATH ship (Small Waterplane Area Twin Hull) with low motion was developed. Previously, the ship was developed for slow motion of a platform invented by Canadian, Frederick G. Creed in 1938, and then he patented the design in 1946. The underwater construction has a torpedo like design. The design has high cost of structure and maintenance leads not developed until 1968. Then, the ship designs were built again in different countries with more sizes, such as; SSC Kaimalino developed in US, and a SWATH ferry was built in Japan.

Catamaran and SWATH ship had significant difference in seakeeping characteristics. Catamaran has a high dynamic motion with an increase of ship speed, mainly the ship running in the head seas. While SWATH ship has good seakeeping with low response, but she has too narrow space for the underwater structure used for

machinery and propulsion system. The difference characteristics motivate engineers to develop a hybrid hull design named semi-SWATH that aims to have combined advantage characteristics of both ships.

The advantages of the multihull ship in seakeeping led the demand of the ships increased. Papanikolaou and Soares (2009) presented a systematically data for high-speed ship and advance marine vehicle type operating in worldwide. He recorded catamaran used widely in the world was 34.1% whilst SWATH 1.2% and semi-SWATH 1.4% of 653 ships recorded throughout the world. The famous aspect of catamaran was caused by the high speed with low cost of structure and ship maintenance than SWATH ship. He estimated that demand of the semi-SWATH would increase along with advances in the technology and design of the ship.

Steven and Parsons (2002) and Folso (2004) presented that demand of high-speed ship is developing not only increasing the ship dimension but also the ship performances in worst weather condition. It was particularly the ship with the required of high comfort in service and safety in ship navigation. However, the purpose of high-speed ship cannot ignore the occurrence of the dynamic motion by the forces acting on the ship hull. It is considerably different to conventional monohull ship where the ship has a low speed and risk in the ship navigation.

Kan (1990) has investigated the dynamics of the monohull ship in following seas, and investigated the ship with surf-riding condition. He has confirmed experimentally that the ship response in surf-riding was nonlinearity. Dand (2006) has also investigated the dynamic motion of Catamaran sailing in following seas. He has conducted seakeeping test in following wave in towing tank. The results showed the ship tends to have a surfing condition when amidships just passing the wave's crest. According to Fang and Chan (2004), during the ship was surfing, the ship's speed increases and then accelerated by the effect of the ship weight force down to the wave trough. The ship will experience a bow-dive condition by a low restoring force at fore hull. Furthermore, Matsuda (2004) described the occurrence of the bow-dive condition always proceeded by a surfing condition that indicated by a rapidly acceleration to the wave trough. This condition can affect the ship in a dangerous situation where the ship can lost of control condition.

The restoring force or stiffness force is highly influenced by the waterplane area of the ship, where the force is increase with an increase of the area. Three different waterlines for high-speed were showed in Figure 1.1. Monohull ship has highest waterplane area, Catamaran, and SWATH ship as the smallest one. It indicates the tendency of the bow-dive occurrence by monohull, Catamaran, and SWATH ship.

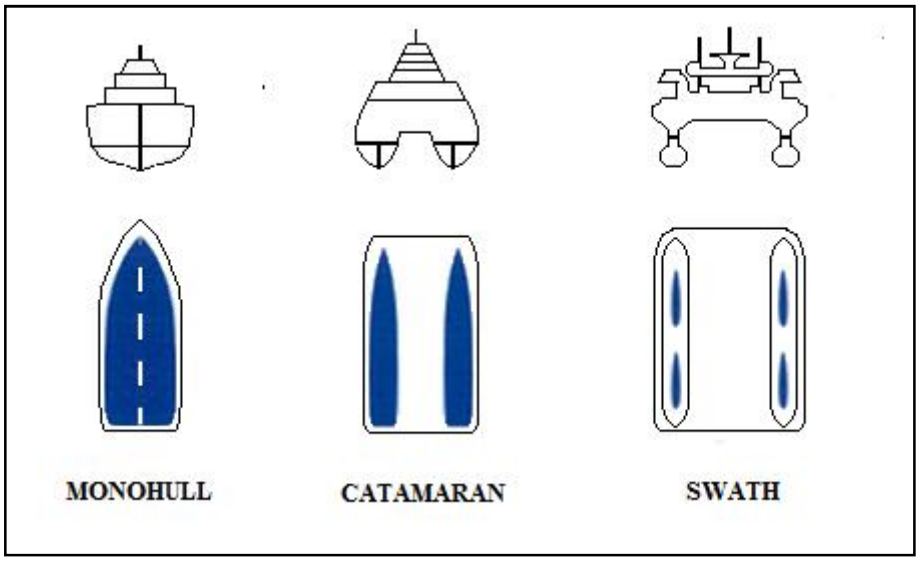


**Figure 1.1** Three types of displacement hull ship and their waterline's shape (www.abeking.com).

The low restoring force, particularly at the bow hull might be a dominant factor to the occurrence of the bow-dive condition. Design of SWATH ship with small waterplane area cannot provide a sufficiently high restoring force relatively to the ship displacement. In addition, the inertial mass of surging motion increase during the ship is surfing. In such condition, the bow can be submerged even it may find the foredeck is being immersed. This condition encourages the researchers to reduce the condition by attaching some additional devices such as fin stabilizers to increase the damping and lift force. The fin stabilizer installed at lower hull as shown in Figure 1.2.

Another way to reduce the bow-dive effect is to use additional structure of bow flare as presented by Katayama et al. (2003). The bow flare increases the restoring force when the bow is immersed in the wave. The bow flare shape likes 'V'

means the waterplane area increase by the increase of the draft and the buoyancy. It is different from the fin stabilizer, where the fins can compensate the vertical force by lift force. The force is influenced by the water velocity flowing around the fin, indeed the ship speed was assumed equal to the water velocity as explored by Naito and Isshiki (2005b) and Djackov (2005). Those efforts aim to increase the ship seakeeping behavior through introducing parameters of added mass, damping, and restoring force influencing on the ship motion characteristics. Fang and Yang (2002) have studied the ship characteristics of heave and pitch motion in following sea by effect of the active fin stabilizer. However, they did not analyze the effect of the ship weights and the ship surfing the wave trough, whilst the surfing condition takes a significant effect in the ship motion.

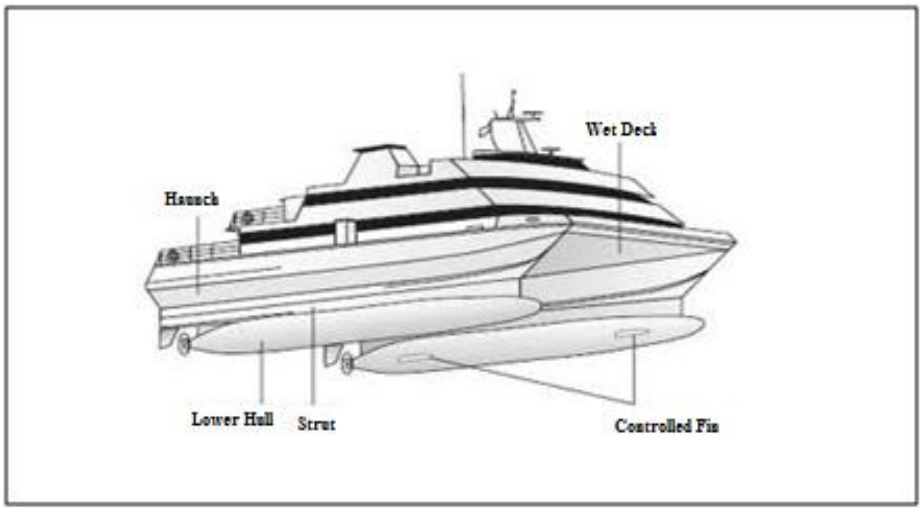


**Figure 1.2** Small Waterplane Area Twin Hull, SWATH with controlled fin stabilizer (www.swath.com).

## 1.2. Problem Statements

The ship may experience surfing condition in following sea when the amidships was just passing the wave crest at the same time the ship's speed and the wavelength slightly higher than the wave velocity and the ship length. The ship speed will increase due to the weight force effect during the ship on the down slope of wave. The ship was found in rapidly accelerating to the wave's trough and tending

to experience a bow-dive condition, even resulted in the deck-dive. The bow-dive occurs due to the small vertical restoring force of the fore hull ship required to lift the ship bow. According to Dand (2005), although taking water over the bow is common in all ships, bow-dive is notable for the fact that it can cause all ways to be lost, the ship will experience a severe bow-dive, deck-dive, and restrained to surge. The worst effect of the condition can decrease the ship performance where it can increase the load of the ship immediately. This problem has been explored by Froehlich et al (2005). Some investigations were conducted including of increasing the displacement of flares, addition of flare structures at the bow of the ship, and application of fixed fin's stabilizer at the ends of the ship. The fins used to increase the lift force and damping force compensating the low buoyancy force at the ends of semi-SWATH hull.

Umeda (1990) and Spyrou (1995, 1996) simulated the ship running in following wave with low encounter frequency and the ship with a dynamic nonlinear response. The nonlinear response occurs at near of the wave's crest. However, using mathematical model in investigation of the ship response at the wave's crest in frequency domain will not figures the effect of parameters changed. The ship parameters changed when the ship's speed is changed. This gives the effect of nonlinear ship's response changed. In addition, research on ship response based on frequency domain shows that the change of particularly encounter frequency also changes the ship characteristics.

## 1.3. Research Objectives

Based on statement of the problem above, the objectives of this research leads;

a. To develop the mathematical model in time domain with respect to parameter changed.
b. To analyze the effect of fin stabilizer on deck-dive, heave, and pitch.

c. To propose a strategy used to reduce the emergence of bow-dive in following seas.

## 1.4. Research Scopes

In order to focus the research on the track of the objectives, some scopes of the research were listed as follows;

a. Develop a simulation program for vertical and longitudinal ship motion in regular waves.
b. Develop a real time programming for fin stabilizer controller used in seakeeping test.
c. Validate the simulation program using seakeeping test data in following seas with regular waves
d. Analyze the ship seakeeping performance and obtain the ship characteristics in following sea.

## 1.5. Research Outline

This research follows a systematic procedure to study the seakeeping performance of the semi-SWATH in following seas using an active fin stabilizer. This research follows a set organization as following;

Chapter 1: This chapter describes background, objectives, and scopes of the research. The research organization was structured to as guidance in whole of research reports.

Chapter 2: This chapter describes a brief history of multihull ship and ship characteristics in sea waves. Some reviews of research of the multihull ship, mathematical model, and control method applied in seakeeping as well as application of appendages on the ship.

Chapter 3: This chapter describes the methodology applied in this research to meet the objectives of the research. The ship motion model and the numeric method used in simulation program and the way of validation the program as an approach to ensure the simulation results in reliable used for analysis, and study the ship performance.

Chapter 4: This chapter describes the basic mathematical model used in arranging the model of surge, heave and pitch motion. The chapter presents calculation of force and moment of fin stabilizers and integration the added mass, damping and stiffness coefficient. The ship motion model presents in time-domain simulation.

Chapter 5: This chapter describes the numerical simulation model developed in MATLAB and Simulink-MATLAB using the mathematical model developed in the previous chapter. The control of pitch motion also describes to regulate the ship motion using active fin stabilizer as ship motion actuator.

Chapter 6: This chapter describes the seakeeping test in following wave such as the seakeeping test procedure, type of test, test equipment, model and fin stabilizer, and control and measurement system. The seakeeping test results would be used in validation of the numerical simulation program.

Chapter 7: This chapter describes a validation of the numerical simulation program and parametric study conducted to evaluate the ship characteristics in following wave. The ship characteristics studied is a related to prevent the bow-dive and foredeck to be immersed. The parametric relations of waves to ship are simulated in time domain, and then the parameters relations were showed in some graphs.

Chapter 8: This chapter describes the results of parametric relation of the ship response were elaborated in discussion and in future work of the related research.

Chapter 9: This chapter describes the conclusions of the research and future works for the next research.

## 1.6. Concluding Remarks

Semi SWATH was a fast ship created from the combination of catamaran and SWATH ship. Both ship's designs were famous with the advantaged characteristic. Combination of both designed aims to have advantage characteristics of both ship designs. However, in following wave, the ship has a tendency to experience bow-dive in which the ship has a low restoring force at bow. Fin stabilizer is one of the solutions can be used to improve her performance. Investigation of the solutions was required to identify, and solve the problems. The next chapter is reviews of literatures described to meet the research objective.

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