HYDRO-RESPONSE OF GRID-LIKE FLOATING STRUCTURE SUBJECTED TO A MONO-DIRECTIONAL FLOW

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To Jesus Christ, my Lord

To my beloved mother

My beautiful family

My faithful friends and fellow researchers

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ABSTRACT

Harvesting hydrokinetic energy from flowing water in rivers requires construction of special structures. The obstacles that need to be considered in designing such structures include shape, size constraints and challenges imposed by the river such as unsteady velocity and pressure. The aim of the current study is to investigate the hydraulic response of the grid-like floating structure subjected to mono-directional flow at different velocities. The study also includes the hydro-induced stress distribution pattern to determine the critical areas of stress. The floating structure considered in this study is a combination of a wedge on the front, which is rigidly connected to a grid-like platform supporting 12 hulls at the back. The grid-like platform has been designed to accommodate a set of 8 turbines with 2.3m blade radius each to generate electricity from the river. ANSYS was used in this study to simulate the hydro-responses of the floating structure at 6 different flow velocities. An experiment was carried out to validate the analysis. In this test, a scaled down floating structure model was subjected to running water at various flow velocities. The key parameters such as drag force, pressure, pressure gradient, and wall shear stress were plotted to show their variations to the change in velocity. Axial and shear stress distribution patterns and formation of vortex had also been observed. In general, both the drag force and maximum pressure increase quadratically with velocity. Formation of vortices is observed behind the wedge and each hull. These vortices become more apparent with the increase in velocity. Strips of large wall shear stress are observed at the wedge and on the first row hulls, where maximum von-Mises stress occurred at the wedge. These parts of the floating structure may require special attention in design. For practical convenience, a series of equations, in terms of various hydro responses useful for design purposes, has been determined as the main contribution of the study.

ABSTRAK

Proses untuk mendapatkan tenaga hidro-kinetik daripada aliran air sungai memerlukan pembinaan struktur yang khusus. Perkara-perkara utama yang perlu dititikberatkan bagi membina struktur tersebut termasuklah bentuk, kekangan dan cabaran daripada sungai itu sendiri seperti halaju air dan tekanan yang tidak stabil. Tujuan utama kajian ini adalah untuk mengkaji tindakbalas hidraulik bagi struktur terapung jenis grid yang dikenakan arus sehala pada halaju air yang berbeza. Kajian juga dibuat terhadap taburan tegasan disebabkan oleh aliran air untuk menentukan bahagian struktur yang kritikal. Struktur terapung yang dikaji adalah gabungan struktur baji di bahagian depan yang disambungkan kepada struktur grid yang terdiri daripada 12 pelampung. Struktur grid tersebut telah direkabentuk untuk memegang 8 turbin penjana tenaga yang mempunyai jejari 2.3 m setiap satu. ANSYS telah digunakan untuk membuat simulasi tindakbalas hidro terhadap struktur terapung tersebut bagi 6 halaju air yang berbeza. Ujian makmal juga telah dibuat untuk memastikan kesahihan simulasi dan analisa tersebut. Dalam ujikaji ini, satu model struktur terapung skala kecil telah diuji dalam aliran pelbagai halaju air. Parameter-parameter penting seperti daya seretan, tekanan, cerun tekanan, dan daya ricih dinding telah diperolehi dan nilainya diplotkan untuk melihat perubahan parameter-parameter tersebut terhadap perubahan halaju air. Taburan tegasan paksi dan ricih serta pembentukan vorteks telah diperhatikan. Secara umumnya, kedua-dua daya seretan dan tekanan maksima meningkat secara kuadratik apabila halaju air meningkat. Pembentukan vorteks juga dilihat di belakang struktur baji dan setiap pelampung. Pembentukan vorteks ini semakin jelas apabila halaju semakin tinggi. Jaluran daya ricih yang besar boleh dilihat di bahagian struktur baji dan pelampung di baris pertama. Tegasan *von-Mises* maksima juga berlaku di bahagian struktur baji. Rekabentuk yang lebih terperinci perlu diberikan perhatian pada bahagian ini. Untuk kemudahan praktikal, satu siri persamaan, dalam bentuk tindak balas hidro untuk kegunaan rekabentuk telah dirumuskan sebagai sumbangan utama kajian ini.

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LIST OF SYMBOLS

v_{in}	–	Inlet velocity
v_{min}	–	Minimum velocity
v_{max}	–	Maximum velocity
P	–	Pressure
P_{min}	–	Minimum pressure
P_{max}	–	Maximum pressure
P_{diff}	–	Pressure difference
$\tau_{w,min}$	–	Minimum wall shear
$\tau_{w,max}$	–	Maximum wall shear
$\delta_{x,max}$	–	Maximum deformation in *x*-direction
$\delta_{y,max}$	–	Maximum deformation in *y*-direction
$\delta_{z,max}$	–	Maximum deformation in *z*-direction
δ_T	–	Total deformation
Θ	–	Angle of rotation
$\tau_{xy,min}$	–	Minimum shear stress in *xy*-plane
$\tau_{xy,max}$	–	Maximum shear stress in *xy*-plane
$\tau_{yz,min}$	–	Minimum shear stress in *yz*-plane
$\tau_{yz,max}$	–	Maximum shear stress in *yz*-plane
$\tau_{xz,min}$	–	Minimum shear stress in *xz*-plane
$\tau_{xz,max}$	–	Maximum shear stress in *xz*-plane
σ_{max}	–	Maximum principal stress
σ_{min}	–	Minimum principal stress
σ_{vm}	–	von-Mises stress

CHAPTER 1

INTRODUCTION

1.1 Introduction and Background of Study

Green sources of energy have become more and more favorable in recent years since they are considered more sustainable and environmental-friendly. Cultivation of energy from rivers through hydro-electric dams has proved to be very popular and widely practiced in many countries. Unfortunately, it is known to have a lot of negative impacts especially on environment. Many studies and researches strongly suggest that hydro-electric damns deplete fisheries, degrade aquatic ecosystems and biodiversity in rivers. Part of the mechanism of a dam requires construction a reservoir that submerges forest habitat, wildlife, and human settlements. This will sometimes involve the displacement of residents that spark strong protests by various parties.

This research program was implemented as part of a project called Sustainable Hydrokinetic Renewable Energy (SHRE) – a collaboration between Public Work Department (PWD) and Universiti Teknologi Malaysia (UTM) to study the harvesting of energy from river currents. This project provides an alternative to generating electricity through dams and avoid blockage of flow so that the traffic will not be obstructed. This is especially important in the interior parts of Sarawak where most of the rivers are active passageways for boats, barges, and other means of transportation related to the river.

The floating structure is a combination of various components including a hull set, turbines, and other mechanical as well as electrical components in the turbine system itself. The hulls are arranged to form a grid-like platform, which is connected to a diverter as part of the major components of the whole floating structure. The floating structure is connected to mooring lines which are then be attached to a set of anchoring dead weights placed at the bottom of the river.

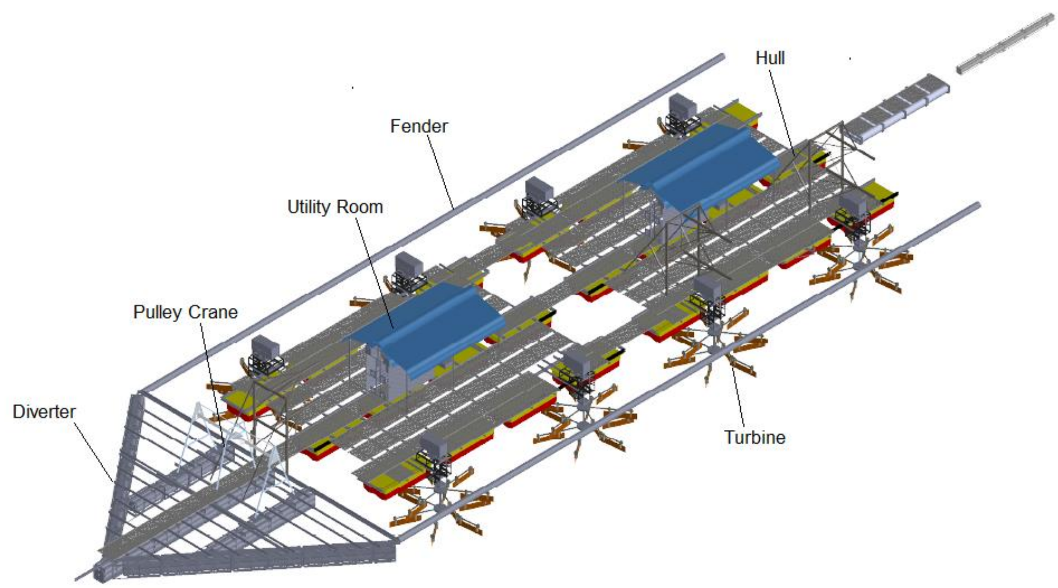

Figure 1.1: The main components of floating structure

The deployment of the floating structure as part of the turbine system that cultivates energy from the river is not without challenges. It has to face a variety of challenges and difficulties right from the conceptual stage to things related to the mooring and structures, environmental challenges, mobilization of materials and deployment on site.

One of the biggest challenges comes from the hydrodynamics of the river flow which is highly unpredictable. The water level for instance changes from time to time depending on the weather especially in the upstream area. This will also lead to varying velocities, which will affect the flow behaviors tremendously. This study will focus on the hydro-responses of the grid-like floating structure at various velocities. Different hydrodynamics may need different structural approaches when it comes to a floating structure in a mono-directional flow.

The outcomes of the study will be very useful in the modification and optimization of structure so that it can serve the purpose and hopefully meet the project requirements. A structural design as a product of thoroughly investigated hydrodynamics is certainly necessary to ensure the safety of the structure and to minimize the risk of a failure.

1.2 Problem Statement

This study is intended to utilize the advancement in the numerical technology to simulate the flow conditions and their effects on a grid-like floating structure especially designed to accommodate a set of hydro-kinetic turbines.

Basically, the aim of the study is to investigate two main things – the effects of the structure towards the flow and the effects of flow towards the structure. In this study, it is very important to note that the structure is considered fully void without taking into account the reinforcement, usually in the form of bulkheads, which is usually present in typical hull structures.

The effects of the structure on the flow of water will include the assessment of the velocity streamlines, drag force, pressure, and wall shear distribution patterns. The velocity distribution is probably the most basic but very important parameter to predict the hydrodynamics of a flow as a whole. It will show how the inlet velocity disperses into streamlines once it hits the floating structure. This will in one way or another give more understanding on why other parameters such as the drag force and pressure behave the way they do around the structure. The velocity streamline will also show the formation of vortices which is known to have significant effects on the hydrodynamics of a floating structure.

The velocity streamline patterns will also indicate the stability of the structure under the given conditions (sway effects). This is especially necessary to ensure that the structure rotates within an allowable angle without obstructing the traffic and endangering the passing motorists.

There are quite a number of forces acting on a floating structure in any mono-directional flow. However, the drag force is known to be the dominant force. The total drag force can be important point of reference in designing the mooring system. The mooring capacity should be sufficient enough to resist against the drag force so that the structure will not be carried away by the river currents. For a more comprehensive assessment of the flow behaviors, the distribution of pressure needs to be investigated too. In this study, the pressure at the surface of water and the pressure exerted on the structure itself will be thoroughly investigated. This will be discussed more in Chapter 3.

Another part of the study is to investigate the effects of the flow on the structure. This part of the study will investigate the shear stress, deformation of structure, maximum principal stress, and von-Mises stress under the given flow conditions. Since the structure is considered void with no reinforcement, huge deformations are expected. It may not really be indicative of the actual performance of the floating structure with reinforcement but the outcomes can become useful references in predicting the hydrodynamic performance at the worse possible scenario and potential failure criterion of the structure. The maximum principal and von-Mises stresses are especially important when it comes to predicting the ability of the structure to take in the load exerted by the flow.

All of these need to be assessed in various inlet velocities so that comparison can be made and projection of values can be executed in future studies and researches.

1.3 Objectives of Study

The aim of this study is to come up with a hydrodynamic assessment for a grid-like platform that is placed in a mono-directional flow. It can be attained by achieving the following objectives:

a) To validate the resulting drag force of the grid-like structure by means of an aquatic experimental test

b) To numerically compute the hydro-responses of grid-like floating structure subjected to a mono-directional flow at different inlet velocities

c) To establish the essential hydro-response relationships and critical parts of the floating structure for future improvement

1.4 Scope and Limitations of Study

This study is subjected to some scope and limitations as described in the following:

a) Since the subject of study is a floating structure in a river, the flow is considered mono-directional unlike in the ocean where the flow of water is multi-directional.

b) The forces that come from the waves are not considered in this study although in the real situation the formation of waves is unavoidable especially when a vehicle passes by.

c) Based on the measurement on site, the maximum water level is 10 m while the width is 150 m. However in the ANSYS analysis, the flow region is set to be 24 m wide, 61 m long and 2 m high. Analysis based on the full size requires too much time and more computer capacity. A pre-analysis indicates that the extra dimension does not give much variation to the results.

d) The drag force and other hydro-responses of the floating structure are analyzed at 0.5 m/s, 1.0 m/s, 1.5 m/s, 2.0 m/s, 2.5 m/s, and 3.0 m/s of velocity. 3.0 m/s has been identified as the maximum velocity in the river where the floating structure will be launched.

e) Only the submerged part is considered in the modeling since only the flow behavior and its effects on the floating structure are of interest.

f) Only major components of the floating structure are modeled. Connection details are excluded.

g) Although the grid-like platform is to hold a set of turbines, the drag force and other hydro-responses that come from these turbines are not considered in this study.

h) The diverter and grid-like hulls set are modeled as rigidly connected to each other.

i) All hydro-responses are investigated at the steady state of the flow. Transient effects are not considered.

1.5 Significance of Study

This study will contribute a lot on the project itself which, if succeeded, will benefit the people in the interior parts of Sarawak. The rivers might be cultivable sources of energy but they come with extreme environmental challenges such as the existence of floating logs and debris that come from the logging areas upstream. The combination of a wedge and grid-like set of hulls is an outcome of a thoroughly studied concept that comes in handy for such environment.

Although the platform was designed for hydro-kinetic turbines in rivers, it can also be emulated for other purposes especially in rivers where logs and debris are known to exert damaging impact on floating structures.

This is a special type of floating structure and testing a full scale in the actual environment will be very costly. This study provides a cheaper solution to the problem by making use of the technological advancement in numerical simulation and validating it with a scaled model test.

This study investigates the hydrodynamics of a flow region, in which a floating structure is placed at different velocities. It also investigates the effects of flow on the structure itself. The velocity is known to change from time to time due to the change in weather and the hydrodynamics of flow change tremendously along. This study provides a structural approach to the ever-changing flow velocities.

The outcomes of this study can also be a useful tool of reference in designing a floating structure and mooring system especially for rivers. There might be a need to minimize the drag force for instance, so the floating structure should be designed in such a way that minimizes the drag force. A thorough analysis on the distribution of load and pressure is of paramount importance when it comes to the optimization of design for a floating structure. This will among others avoid additional costs that come from over-designing. In the mooring design, the study provides useful information especially on the forces that need to be dealt with.

One of the major aims of the study is to ensure the structural integrity of the floating structure when it is faced with environmental challenges that come mostly from the drag force. The analysis investigates the critical areas of the floating structure where failures are most likely to happen so that more attention can be given to these parts.

This study also establishes the relationship between parameters of interest so that they can be used for future projection in similar studies.

Apart from those mentioned above, the outcomes of this study might make good references for future studies especially those related to hydrodynamic and structural integrity of a floating structure in a mono-directional flow.

1.6 Thesis Organization

In short, the study aims to investigate the flow behaviors of a flow region, in which a floating structure is placed and how these behaviors may affect the structure. This is executed by simulating the flow region and the structure using ANSYS analysis. This report begins at the introduction part in Chapter 1 and concludes in Chapter 5.

After the introductory chapter, Chapter 2 presents the literature review that begins with Section 2.1, in which the overview of study describes popular methods in studying the hydro-responses of a floating structure. It also describes how it develops from very physical tests to numerical simulations. The next section in the chapter is Section 2.2 where the categorization of open channels is briefly outlined. Section 2.3

describes the general flow behaviors in open channels. This section focuses on the velocity and pressure distribution in an unobstructed flow. The effects of floating bodies on flow behaviors and vice versa are briefly discussed in Section 2.4. Section 2.5 that follows is dedicated to studies related to this current subject. Chapter 2 ends with the conclusion part in Section 2.6.

Chapter 3 is devoted to the research methodology. It begins by describing the history of the development of Computational Fluid Dynamics (CFD) and how it slowly overtakes the physical model test in assessing a ship's performance. Section 3.2 is the introduction of the grid-like floating structure which is the main subject of research in this study. Here, the major components are briefly described together with the visual presentation of the structure. Section 3.3 describes on how the ANSYS CFX part of the analysis was performed. Each stage from modeling to meshing and application of boundary conditions are briefly described. The next section, Section 3.4, is dedicated to the structural part of the analysis. Here, the material properties used in the analysis are listed. It also describes the meshing and boundary conditions, which are mostly imported from the CFX analysis. Chapter 3 ends with Section 3.5, which is on the validation part. Here the physical scaled model described together with all the necessary measurement details, highlighting the experimental set-up, instrumentation and implementation.

Chapter 4 covers the results of analysis. It begins with the laying out of results for the validation test in Section 4.1. Here the drag forces obtained from the experimental test and CFX are compared. Section 4.2 is dedicated to the results obtained from ANSYS CFX analysis. It covers the results for drag force, velocity streamlines, pressure and wall shear. The next section, Section 4.3, is allocated for the structural part of the analysis results. This section will cover the structural deformation, rotation of angle, shear stress, principal stress and von-Mises stress experienced by the floating structure in response to the flow behaviors.

Chapter 5 offers the conclusion for the research as well as ideas and recommendations for future studies.

REFERENCES

Ahmad Kamal, N.I. (2012). Estimating the Drag Coefficient of Amphibious House in Longitudinal Direction, (JUNE), 103.Univerisiti Teknologi Malaysia : Bachelor's Degree Thesis

ANSYS (2009). ANSYS CFX Solver Theory Guide. *ANSYS CFX Release, 15317*(April), 724–746. https://doi.org/10.1016/j.ijmultiphaseflow.2011.05.009

Asseff, N.S. (2009). Design and Finite Element Analysis of an Ocean Current. Florida Atlantic University : *Masters Thesis*, (August).

Broglia, R., Jacob, B., Zaghi, S., Stern, F. and Olivieri, A. (2014). Experimental investigation of interference effects for high-speed catamarans. *Ocean Engineering*, *76*, 75–85. https://doi.org/10.1016/j.oceaneng.2013.12.003

Chau, S. (2009). Chung Yuan Christian University Study on Flow Induced by Triangular. http://www.pointwise.com/apps/trifin.shtml

Chow, V.T. (1959). *Open Channel Hydraulics*. (George Tchobanoglous, Ed.), *McGraw-Hill Book Company*. McGraw-Hill Book Company. https://doi.org/ISBN 07-010776-9

Connell, K. O. and Cashman, A. (2016). Mathematical & CFD analysis of free floating heave-only body. *2015 International Conference on Renewable Energy Research and Applications, ICRERA 2015*, *5*, 467–471. https://doi.org/10.1109/ICRERA.2015.7418456

Degroote, J., Vierendeels, J., Vepa, S. and Paepegem, W. V. (2011). "Fluid-structure Interaction Simulation of the Breaking Wave Slamming on an Absorber for a Wave-energy Converter." In *EURODYN-International Conference on Structural Dynamics*, ed. Guide De Roeck, G Degrande, G Lombaert, and G Müller, 3062–

3069. Ghent, Belgium: Ghent University, Department of Mechanical construction and production.

Dutta, S., Panigrahi, P. K. and Muralidhar, K. (2008). Experimental Investigation of Flow Past a Square Cylinder at an Angle of Incidence. *Journal of Engineering Mechanics*, *134*(9), 788–803. https://doi.org/10.1061/(ASCE)0733-9399(2008)134:9(788)

French, R.H. (1986). *Open-channel Hydraulics*. McGraw-Hill Book Company. Retrieved from http://www.tvrl.lth.se/fileadmin/tvrl/files/vvr090/Open_Channel_Hydraulic_french.pdf

Fu, S., Moan, T., Chen, X. and Cui, W. (2007). Hydroelastic Analysis of Flexible Floating Interconnected Structures. *Ocean Engineering*, *34*(11–12), 1516–1531. https://doi.org/10.1016/j.oceaneng.2007.01.003

Ge, F., Lu, W., Wu, X. and Hong, Y. (2010). Fluid-structure Interaction of Submerged Floating Tunnel in Wave Field. *Procedia Engineering*, *4*, 263–271. https://doi.org/10.1016/j.proeng.2010.08.030

Ghassemi, H., Mansouri, M. and Zaferanlouei, S. (2011). Interceptor Hydrodynamic Analysis for Handling Trim Control Problems in the High-speed Crafts. *Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science*, *225*(11), 2597–2618. https://doi.org/10.1177/0954406211406650

Gray, A.W. (2003). A Preliminary Study of Trimarans. *West Virginia University*.

Hin, L. S., Bessaih, N., Ling, L. P., Ab. Ghani, A. and Seng, M. Y. (2008). Determination of Apparent and Composite Friction Factors for Flooded Equatorial Natural Rivers. *International Journal of River Basin Management*, *6*(1), 3–12. https://doi.org/10.1080/15715124.2008.9635332

Hoerner, S. F. (1965). Fluid-Dynamic Drag. Retrieved from http://dl.kashti.ir/ENBOOKS/NEW/FDD.pdf

Hygelund, B. and Manga, M. (2003). 'Field Measurements of Drag Coefficients for Model Large Woody debHygelund, Bretagne, and Michael Manga, "Field Measurements of Drag Coefficients for Model Large Woody Debris", 51 (2003), 175–85ris', 51 (2003), 175–85 <http://www.sciencedirect.com/science/article/pii/S0169555X02003355>.

Javanmardi, M.R., Jahanbakhsh, E., Seif, M.S. and Sayyaadi, H. (2008). Hydrodynamic Analysis of Trimaran Vessels. *Polish Maritime Research*, *15*(1), 11–18. https://doi.org/10.2478/v10012-007-0046-5

Kim, B. W., Young Hong, S., Kyoung, J. H. and Kyu Cho, S.K. (2007). Evaluation c Bending Moments and Shear Forces at Unit Connections of Very Large Floating Structures Using Hydroelastic and Rigid Body Analyses. *Ocean Engineering*, *34*(11–12), 1668–1679. https://doi.org/10.1016/j.oceaneng.2006.10.018

Kwon, Y. W. (2014). Dynamic Responses of Composite Structures in Contact with Water while Subjected to Harmonic Loads. *Applied Composite Materials*, *21*(1), 227–245. https://doi.org/10.1007/s10443-013-9363-2

Lalander, E. and Leijon, M. (2009). Numerical modeling of a river site for in-stream energy converters. *8th European Wave and Tidal Energy Conference*.

Lee, D. and Son, I. (2012). Optimal Shape Design of a Floating Body for Minimal Water Wave Forces. *Proceedings of the Institution of Mechanical Engineers Part C-Journal of Mechanical Engineering Science*, *226*(C3), 752–762. https://doi.org/Doi 10.1177/0954406211415200

Lee, K. and Lee, P. (2016). Nonlinear Hydrostatic Analysis of Flexible Floating Structures. *Applied Ocean Research*, *59*, 165–182. https://doi.org/10.1016/j.apor.2016.05.016

Ma, S. (2012). Studies of Composite Multihull Ship Structures Using Fluid Structure Interaction, (August). Retrieved from http://gradworks.umi.com/35/30/3530709.html

Ma, S. and Mahfuz, H. (2012). Finite Element Simulation of Composite Ship Structures with Fluid Structure Interaction. *Ocean Engineering*, *52*, 52–59. https://doi.org/10.1016/j.oceaneng.2012.06.010

Mandara, A., Russo, E., Faggiano, B. and Mazzolani, F. M. (2016). Analysis of Fluid-structure Interaction for a Submerged Floating Tunnel. *Procedia Engineering*, *166*, 397–404. https://doi.org/10.1016/j.proeng.2016.11.572

Mara, B. K., Mercado, B. C., Mercado, L. A., Pascual, J. M. and Lopez, N. S. (2014).

Preliminary Turbulence Model Validation for Flow Across Rotating Cylinders using ANSYS CFX. *International Conference on Humanoid, Nanotechnology, Information Technology, Communication and Control, Environment and Management (HNICEM)*, (November), 1–5. https://doi.org/10.1109/HNICEM.2014.7016266

Marzban, A., Lakshmiraju, M., Richardson, N., Henneke, M., Wu, G., Vargas, P. M Oakley, O. (2012). Offshore Platform Fluid Structure Interaction Simulation. *Proceedings of the ASME 2012 31st International Conference on Ocean, Offshore and Arctic Engineering*, (August 2016). https://doi.org/10.1115/OMAE2012-83472

Matveev, K. I. and Bari, G. S. (2015). Effect of Deadrise Angles on Hydrodynamic Performance of a Stepped Hull. *Proceedings of the Institution of Mechanical Engineers, Part M: Journal of Engineering for the Maritime Environment*, *230*(4), 616–622. https://doi.org/10.1177/1475090215613813

Mizine, I., Amromin, E., Crook, L., Day, W. and Korpus, R. (2004). High-speed Trimaran drag: Numerical Analysis and Model Tests. *Journal of Ship Research*, *48*(3), 248–259.

Molland, A. F. and Utama, I. K. A. P. (2002). Experimental and Numerical Investigations into the Drag Characteristics of a Pair of Ellipsoids in Close Proximity. *Proceedings of the Institution of Mechanical Engineers, Part M: Journal of Engineering for the Maritime Environment*, *216*(107), 107–115. https://doi.org/10.1243/147509002762224324

Munson, B. R., Young, D. F. and Okiishi, T. H. (2013). *Fundamentals of Fluid Mechanics* (7th ed.). WileyPLUS.

Rad, M., Seif, M. S., Nakisa, M. and Asgari, M. (2005). Hydrofoil Attack Angle Effect on Hydrodynamic Resistance of Semi-Planing Catamaran. *ASME 2005 24th International Conference on Offshore Mechanics and Arctic Engineering*, *2*, 695–702. Retrieved from http://proceedings.asmedigitalcollection.asme.org/proceeding.aspx?articleid=1575547

Smoker, B. (2012). CFD Escort Performance Prediction Method. University of Florida : *Masters Thesis*.

Sturm, T. W. (2011). *Open Channel Hydraulics* (2nd ed.). London, United States: McGraw-Hill Education - Europe.

Tsang, K., Bruschi, G., Nishioka, T. and Wang, R. (2003). A Comparison of Analytical Methods Drag Coefficient of a Cylinder. Retrieved from http://sv.20file.org/up1/916_0.pdf

Venugopal, V., Varyani, K. S., and Westlake, P. C. (2009). Drag and Inertia Coeffic for Horizontally Submerged Rectangular Cylinders in Waves and Currents. *Journal of Engineering for the Maritime Environment*, *223*(1), 121–136. https://doi.org/10.1016/j.buildenv.2006.10.027

Wallenberger, F.T., Watson, J.C. and Li, H. (2001). ASM International Handout, *21*(Ref 19), 1–6. https://doi.org/#06781G

Yan, J., Koronbenko, A., Deng, X. and Bazilevs, Y. (2016). Computational Free-surface Fluid Structure Interaction with Application to Floating Offshore Wind Turbines. *Computers and Fluids*, *141*, 155–174. https://doi.org/10.1016/j.compfluid.2016.03.008