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Numerical simulation of floating airboat: Estimation of hydrodynamic forces

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Abstract: Airboat motion is always a specific maneuver operation. The flow around the airboat and the forces acting on it are quite different from those for a ship in normal act. By solving the unsteady Reynolds- Averaged Navier-Stokes (RANS) equations, the transient flow field around an airboat undergoing unsteady motion is simulated and the varying hydrodynamic force in effect of the different currents acting on the hull is evaluated in this article. OpenFoam 2.1.0 and extended toolbox will be used to do simulation. The numerical results obtained with K-omega shear stress transport turbulence models and the volume of fluid method as the suitable turbulence model are analyzed and compared with experimental results.

Keywords: The VOF Method, Finite Volume, Dynamic Mesh, Airboat, Turbulent Model

1. Introduction

Nowadays, because of the high speed motion's requirement, the airboat plays an important role in the marine transportation. Therefore, a design process for this type of boat is needed. The main problem is to determine exactly the forces and the moments acting on the hull body of an airboat.

To solve this problem, there are two solutions. One is to use the experiments, the other is the numerical simulation based on a physical models. An experiment requires many controlled conditions such as a model basin, the electrical equipment, etc. However there are not many facilities in Vietnam that can satisfy this request. In fact, we actually find a water tunnel at Vinashin Group, and another one at the University of Transport and Communications. But both of them can do the tests for the hydrodynamic forces of a boat-model in the limit of the Froude number about 1.0 (note that the Froude number limit of an airboat can be 2.0). That is the reason why the numerical simulation is the proper choice to find the hydrodynamic forces acting on an airboat.

The objective of this article is to determine the forces acting on a two-seat airboat (see Figure 1), getting from our research project [1], by using the numerical simulation method. And based on this model, a numerical model for the airboat can be built for the unsteady conditions.

2. Setup A Numerical Model for Airboat

2.1. Geometry and Meshing

Figure 1 shows the 3D layout of the two-seat airboat. This airboat has a hull body in the V shape.

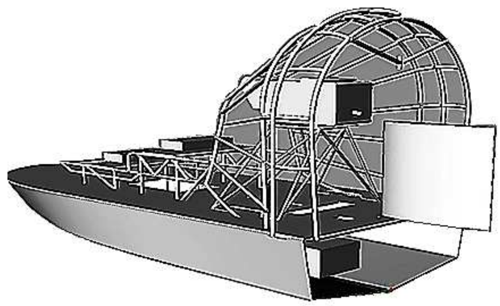


Figure 1. *3D model of the two-seat airboat*

The simulation domain in Figure 2 is divided into three zones [2]: the generating zone, the main zone and the relaxation zone. The generating zone creates water wave (the wave in this zone is in imposition. In spite of a mesh quality or an impact of physical properties, it is formed at what we define). The main zone influences the generating zone in the way in which the wave is set freely by RANS. The relaxing zone imposes the wave again in order to help reducing this wave to zero.

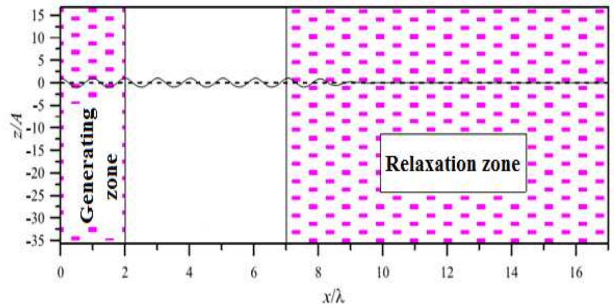


Figure 2. *Simulation domain*

The mesh in this case is generated automatically by snappyHexMesh in OpenFoam [3]. Its format is hexa with octree strategy. At first, the "blockMesh" tool is used to create a base mesh. Then the "snappyHexMesh" will be added the airboat surface to STL format and define a refined volume to increase the mesh quality in the necessary zones (see Figure 3).

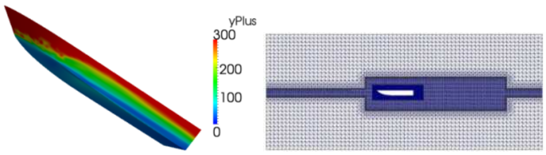


Figure 3. *The airboat's mesh.*

2.2. Solver and Data Record

The Navier-Stoke equations are set to descript the motion of the fluids in form of partial differential system:

$$\rho\left(\frac{\partial U}{\partial t}+U.\nabla U\right)=-\nabla p+\nabla T+f \tag{1}$$

$$\frac{\partial \rho}{\partial t}+\nabla.(\rho U)=0 \tag{2}$$

Multiphase flow solver differs from the compressible solver for single phase flow in that it still keeps the variable ρ in both momentum and mass conservation equation. The volume of fluid (VOF) method is applied to determine ρ. VOF method is a technique which helps to track the free surface distinguishing the different phases of the flow. In this case, they are the liquid phase (water) and the gas phase (air).

VOF method tracks the volume of each fluid in each cell by color function C:

$$\frac{\partial C}{\partial t}+\frac{\partial U_i}{\partial x_i}C=0 \tag{3}$$

The interpolated density function and viscosity function are [4]:

$$\rho=\rho L(1-C)+\rho DC \tag{4}$$

$$\mu=\mu L(1-C)+\mu DC \tag{5}$$

Function C has value between 0 and 1. Value at limit shows that cell just content one phase. Cell has the interface of separating phases with the other value of function C. The interface between the two phases is reconstructed from the volume fraction data in iteration.

To predict the effects of turbulence, we use SST k-ω model. This turbulence model is a two-equation eddy-viscosity model. The shear stress transport (SST) formulation combines the good of two. The use of a k-ω formulation in the inner parts of the boundary layer makes the model directly usable all the way down to the wall through the viscous sub-layer hence the SST k-ω model can be used as a Low-Re turbulence model without the extra damping functions. The SST formulation switches to a k-ε behavior in the free-stream and thereby it avoids the common problem of the k-ω model (the k-ω model is too sensitive to the inlet free-stream turbulence). Note that the authors who use the SST k-ω model often merit it for its good behavior in adverse pressure gradients and separating flow. The SST k-ω model does produce a bit too large turbulence level in a region with large normal strain such as the stagnation region and some regions with strong acceleration. This tendency is much less pronounced than with a normal k-ε model.

Equation (6) is the turbulence kinetics energy equation [4].

$$\frac{\partial k}{\partial t}+U_j\frac{\partial k}{\partial x_j}=P_k-\beta * k\omega+\frac{\partial}{\partial x_j}\left[(\nu+\sigma_k\nu_T)\frac{\partial k}{\partial x_j}\right] \tag{6}$$

And the specific dissipation rate equation is shown in (7) [4].

$$\begin{aligned}\frac{\partial \omega}{\partial t}+U_j\frac{\partial \omega}{\partial x_j}&=\alpha S^2-\beta\omega^2+\frac{\partial}{\partial x_j}\left[(\nu+\sigma_k\nu_T)\frac{\partial k}{\partial x_j}\right]\\&+2(1-F_1)\sigma_{\omega,2}\frac{1}{\omega}\frac{\partial k}{\partial x_j}\frac{\partial \omega}{\partial x_j}\end{aligned} \tag{7}$$

The forces and moment acting on the boat surface are sum of these on each element.

$$\begin{aligned}F&=F^p+F^v=\sum f_i.A_i\\M&=M^p+M^v=\sum f_i.A_i l_i\end{aligned} \tag{8}$$

Force and moment coefficient obtain by dividing force and moment above by referent values of wet area and boat length.

$$C_f=\frac{F}{\frac{1}{2}\rho L.V^2.Aref},C_m=\frac{M}{\frac{1}{2}\rho L.V^2.A_{ref}.L_{ref}} \tag{9}$$

The simulation is done by using Open FOAM. Because Open FOAM itself does not have any wave generation boundary or initial zone, a wave simulation could be generated by an open source extended toolbox [5]. It is used to generate and absorb the free surface water waves. Currently, the method applies the relaxation zone technique. Many wave theories are supported and the relaxation zones can take the arbitrary shapes. The library "waves2Foam" comes also with pre- and post-processing utilities in order to use the free surface flows within the fields of coastal, marine and maritime engineering.

All procedures mentioned above have been written as a C++ header file called *relaxation. H* which is added to the source code of the inter Foam and the inter DyMFoam. The two modified solvers, named wave Foam and wave DyMFoam. These new solvers remain the ability of simulating two phase flows coupled with mesh motion in six degrees of freedom and enable us to generate and dissipate waves in the wave tank with and without floating object.

2.3. Test Cases

In order to validate the new solver and to prepare for boat simulation, two test cases are built. The first describes a regular water wave in free surface. So a wave which has a wave height of 0.0238 m and a wavelength of 0.78 m is simulated and the result will be compared with the one of Prof. Dr. José (Moreil) [6]. In fact, the result obtained from the new solver is really good after *eta\Amplitude* (eta is wave height over time) of 3.5 (see Figure 4). Therefore, the object should be imposed in the position which is far from the wave generation of 1.5 λ to 2 λ for similar wave mesh (see Figure 5).

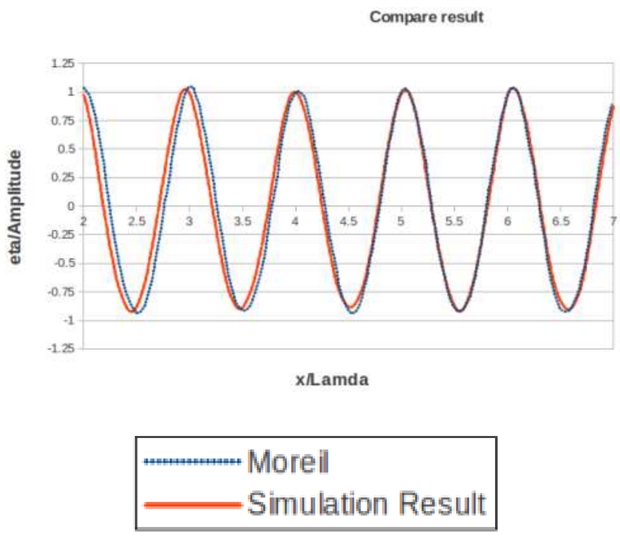
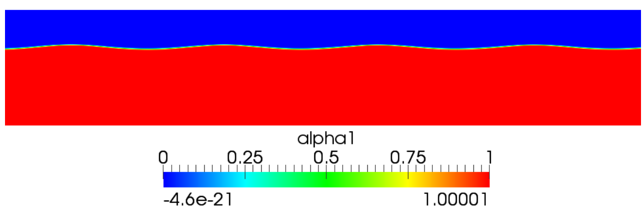


Figure 4. *Regular wave simulation in compared with Moreil result*



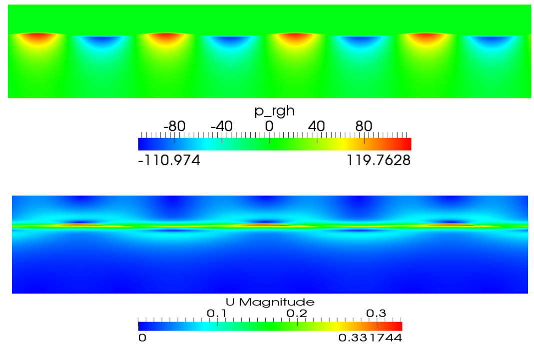


Figure 5. *Phase, dynamic pressure and velocity distribution*

The second test case is the simulation of a fixed cylinder in water wave. The purpose of this test is to verify the wave's impact on the fixed object, and to check that the wave works properly in the domain containing it. A cylinder having a diameter of 0.25 m, a length of 0.12 m, is posed in a water tank which contains the wave having a wave height of 0.25 m and a period of 1.646 s (see Figure 6).

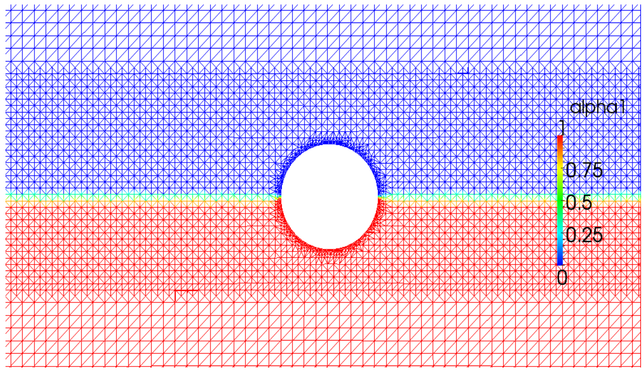


Figure 6. *Phase distribution at initial condition*

The obtained result is compared with the one of Hyo-Jae Jo [7]. The relative force is described by F_o ($F_o = F_z/(g\rho \pi D^2 l/4)$) and F_z is a force on the cylinder resulting from the pressure acting on the surface calculated in the vertical direction. It can be seen that a good agreement is achieved with our model, the experimental data and the theoretical forces (see Figure 7 and Figure 8).

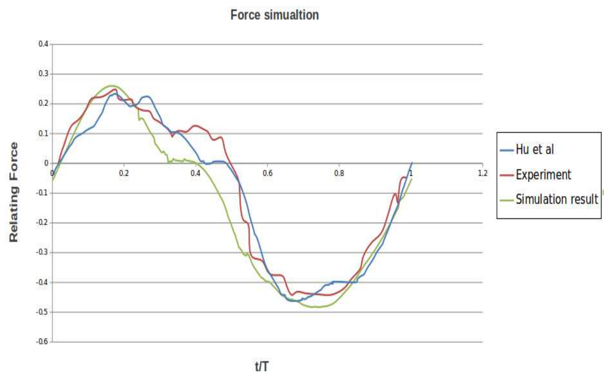


Figure 7. *Relative force on cylinder*

Our model can be used now for the airboat simulation.

Table 1. *Flow properties*

Simulation result		Experiment		Static simulation case	
		Value	Error	Value	Error
Cd viscous	0.00496	0.006	17.3%	0.0056	11.4%
Cd pressure	0.02321	0.025	7.2%	0.0234	0.8%
Cd total	0.02817	0.031	9.12%	0.0290	3%

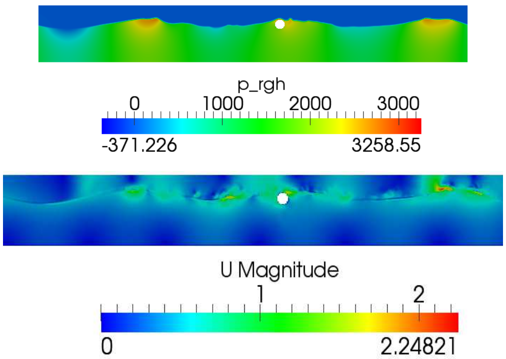


Figure 8. *Pressure and velocity distribution around cylinder*

3. Airboat Simulation and Results

3.1. Airboat without Wave Effect

In this case, the airboat is set at velocity of 3 m/s. The purpose of this simulation is to validate its motion in the water without wave. This velocity will be used as contact of the airboat and the current in case of wave. Despite of the low speed operation condition, the experiments show that the highest drag coefficient is applied.

The result is shown in following Figure 9.

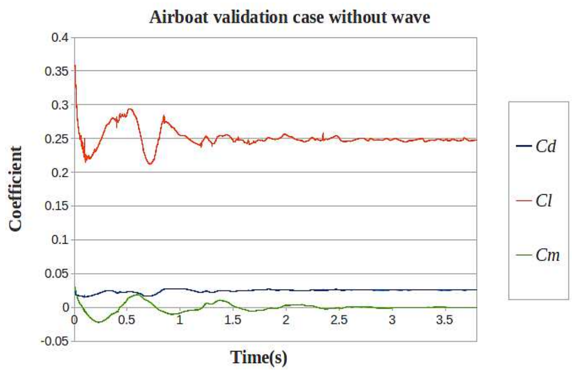


Figure 9. *Force and moment coefficients in case of without wave*

Table 2. *Comparing the result with experiment and static simulation*

Velocity of flow U (m/s)	Reynolds numberRe	Weber number We	Froude numberFr
3	9.5×106	660	0.51

This result is compared with the one from the research project [1]. It confirms that the simulation is satisfied with the requirements of a numerical simulation. For the total drag coefficient (C_d total), the difference between the experiment and the simulation is about 9.12%. The proper resolution of mesh can help to catch the free surface deformation and in this case, the octree hex mesh is a good choice for a dynamic mesh in OpenFOAM. However some refined region is not necessary so the surface near the boat is not a good one (see Figure 10).

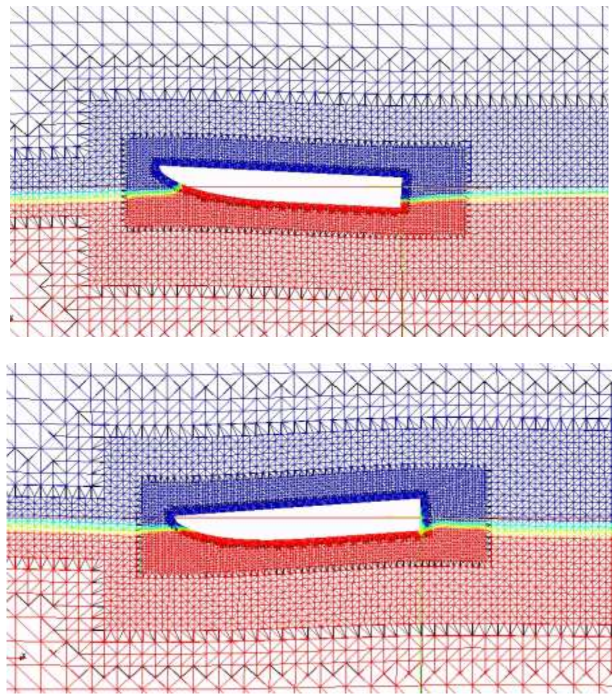


Figure 10. *Mesh motion.*

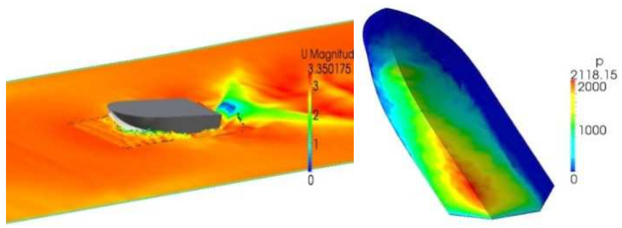


Figure 11. *Distribution of velocity and pressure around the airboat*

The free surface acts like a real case when the boat moves in the water. Behind the boat, there is Kelvin wave. This Kelvin wave has the angle of shock wave of 52 degree which is accordant to the experiment. The pressure distribution around the airboat does not change. The highest pressure is distributed at the bottom of the airboat caused by the flow interaction at the tail (see Figure 11). It means that in motion more force is applied to the tail than the other position.

3.2. Airboat with Wave Effects

In this case, the wave has the amplitude (A) of 0.05 m, the frequency (ω) of 1.68 rad/s and a number (k) of 1.61. In order to compare with the case without wave, the mean current flow is maintained at speed of 3 m/s.

The simulation's results are shown in Figure 12 and Figure 13. Because of the wave's effect, the dynamic stable state gives a wide range of force coefficient and moment coefficient.

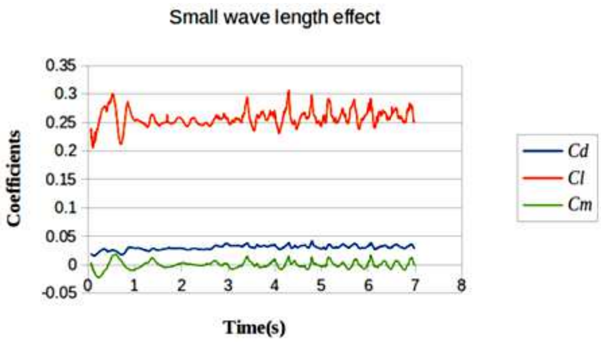


Figure 12. *Force and moment coefficients acting on the airboat*

Note that at the beginning the airboat is set up as the case without wave. Therefore its drag coefficients, including the friction and the pressure components, react as the airboat without wave. When the wave reaches the airboat position, it begins to vibrate along with wave (see Figure 14).

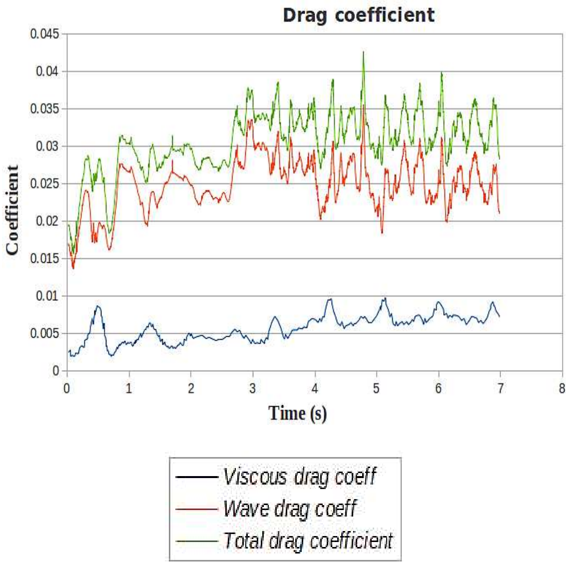


Figure 13. *Drag coefficients*

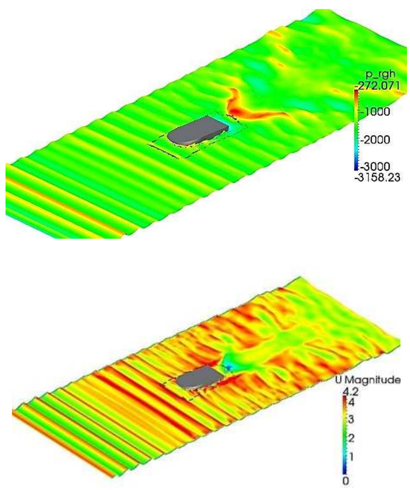


Figure 14. *Dynamic pressure and velocity distribution with wave effect*

3.3. Analysis Simulation Results

It is admitted that in comparison with the case without wave, the wave makes an increase of the values of drag coefficient, and also the amplitude of the vibration in lift coefficient and moment coefficient. The above figures show that the value of lift coefficient increases because the wave's energy makes the water surface become higher than normal. Furthermore, the area of the airboat's surface that contacts with the water varies. So every contact between wave and boat, the wave drag increases.

Table 3. *Compare drag coefficient of airboat in cases of without wave and having wave*

	Without wave	With wave	Difference
C_d viscous mean	0.00496	0.0069	+28.1%
C_d pressure mean	0.02321	0.02512	+8.2%
C_d total	0.02817	0.03202	+13.6%

Table 3 shows the drag coefficient of the airboat in case of having wave and without wave. The result indicates that the wave causes the increase of the surface velocity. Then the different velocity is high. Therefore the viscous drag is high too. Although the increase of the viscous drag ratio is higher than the one of the pressure drag, its actual value is smaller. Note that a maximum total drag coefficient is about 0.04 in the case of wave condition.

4. Conclusion

In this article, based on an open library the new solvers are created and used to solve the problems of a constrained motion in multiphase flow. The results obtained from the simulation show that the new solvers are suitable and can be used to analyze the motion of an airboat model in condition having wave or without wave.

The drag coefficient in wave condition becomes very high in comparison with the case without wave. Therefore, thank to this computational model, we can simulate many types of water's wave and can extend it easily. And furthermore the use of the dynamic mesh and the 6-DOF equations helps improving considerably the accuracy of the numerical simulation of floating airboat for the hydrodynamic forces and moments.

Acknowledgment

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Nomenclature

K	Turbulent kinetic energy
ω	Specific dissipation rate
U_i	Velocity
x_i	Position (Cartesian reference)

P	Pressure
ρ	Mass density
μ	Dynamic viscosity
N	Kinetic viscosity
C_l	Lift coefficient
C_d	Drag coefficient
C_m	Moment coefficient
pL	Gas flow
pD	Liquid flow
C	Color function
σ	Normal stress
S	Shear stress
F, P, α, ϕ	Closure coefficients and auxiliary relation
n_i	Normal vector of surface element
T	Stress tensor
A_{Ref}	Wet area of the boat in static balance
L_{Ref}	Length of boat

References

[1] Ngo Khanh Hieu. (2012). *Two-seat Airboat Design*, KC.03.TN18/11-15, Research project of Vietnam Ministry of Science and Technology.

[2] Z. Z. Hu, D. M. Causon, C. G. Mingham, and L. Qian. (2011). *Numerical simulation of floating bodies in extreme free surface waves*, Centre for Mathematical Modelling and Flow analysis, School of Computing, Mathematics and Digital Technology,The Manchester Metropolitan University, Manchester, M1 5GD, UK.

[3] S. R. T. a. D. H. Bj¨orn Wind´en. (2012). *Validating Force Calculations using OpenFOAM on a Fixed Wigley Hull in Waves*, Fluid-Structure Interactions Research Group University of Southampton, Southampton, UK.

[4] K. M. Kalland. (2012). *A Navier-Stokes Solver for Single- and Two-Phase Flow*, Faculty of Mathematics and Natural Sciences University of Oslo.

[5] https://github.com/ogoe/waves2Foam

[6] P. A. José Manuel Paixão Conde. (2012). *Contribuição para a validação do código numérico OpenFOAM em escoamentos com superfície livre*, Universidade Nova de Lisboa, Faculdade de Ciências e Tecnologia, 2012.

[7] S.-J. L. a. J.-E. C. Hyo-Jae Jo. (2011). *A study of flow structure of bichromatic waves*, Division of Naval Architecture and Ocean Systems Engineering, Korea Maritime University, Busan 606 -791, Korea.

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