Journal of Advanced Research in
Numerical Heat Transfer

Journal homepage:
https://semarakilmu.com.my/journals/index.php/arnht/index
ISSN: 2735-0142

A Proposed Seaplane Float in Water Entry Problem and Landing in Waves using Particle Based Method

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ARTICLE INFO

Article history:
Received 8 March 2023
Received in revised form 17 April 2023
Accepted 15 May 2023
Available online 30 June 2023

Keywords:
Seaplane float; Water entry; Landing waves; Particle based method; Smoothed Particle Hydrodynamics; DualSPHysics

ABSTRACT

Seaplane is the newly transportation mode which is developed in the Indonesian Archipelago Region. Originally, the seaplane is equipped by pair of the floats in function to withstand the aircraft load and maintain the seaplane on the water stably. One of the critical moments in the seaplane operation is in the landing phase in waves. The failure in the float performance can be led into severe conditions, even the capsize. In this paper, the aims are to determine the water impact characteristics and response of the proposed seaplane float by implementing the water entry case, calm water landing, and when landing in the periodic waves condition. The numerical model was developed using DualSPHysics based on Smoothed Particle Hydrodynamic to obtain more realistic and accurate prediction of the pressure, velocity fields, and water spray motion with droplets in complex shape of the float. According to numerical results and reproducible experimental data in this study, the 2D water entry and 3D calm and waves water problem were applied to reproduce the detailed characteristics of the interaction between the proposed seaplane float and the water surface with splashing. The paper showed that the developed model could be a useful tool to design the seaplane float for Indonesian seaplane in the future.

1. Introduction

Development of the seaplane in Indonesia enters a new phase, supported by the manufacture activities of the designed 19-seat passenger aircraft. This aircraft type which is illustrated as Figure 1, is utilized to several main functions consist of passenger transport, troop transport, logistic transport, medical evaluation, surveilling, and rescue. To fulfill the needs of the flexible transportation which connect the wider area in Indonesia, the aircraft is projected to be modified to amphibious aircraft or seaplane.

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https://doi.org/10.37934/arnht.13.1.3138

Fig. 1. 19-passenger aircraft in Indonesia [1]

The main part which requires to be adjusted is the replacement from the landing gear to floats as shown in Figure 2. In general, floats are an equipment installed to withstand the load of an aircraft and maintain the seaplane stably on the water surface as shown in Figure 3.

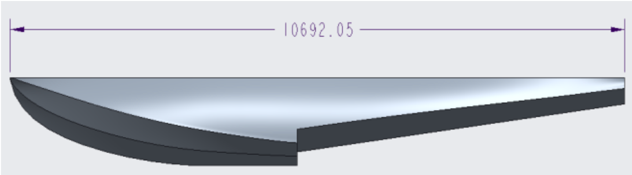


Fig. 2. Floater design of seaplane

Fig. 3. Seaplane illustration (not original design, redrawn based on the pictures)

Landing is one of the critical moments which needs to be assessed precisely. The failure in that processes possibly lead to serious accidents such as structure damage, instability, and even capsizing. Recently, the numerical and experimental studies of water entry problem for various objects was conducted by Del Buono *et al*., [2], Oger *et al*., [3], Chen *et al*., [4], Farsi and Ghadimi [5], and Yang *et al*., [6]. In contrast with the aircraft ditching phenomena, that is assumed as emergency landing accidentally, the seaplane is destined to conduct the landing phase in the water surface. Several aspects of ditching were assessed by Woodgate *et al*., [7] and Guo *et al*., [8]. The numerical research about proposing motion during ditching in blended wing body (BWB) aircraft was introduced by Zheng *et al*., [9] and Xiao *et al*., [10]. The proposed seaplane float has been originally inspired from Syamsuar *et al*., [11], who studied the numerical simulation using Computational Fluid Dynamics (CFD) method to determine the hydroplaning resistance. Ardiansyah and Adhitya [12] conducted the static simulation of the seaplane float by using landing speed parameter. However, according to the previous papers, the dynamic simulation needs to be assessed to define more accurate result of the water impact between floaters and free surface. Since the seaplane project has been established in Indonesia, the matured studies in many technical aspects are needed to be conducted comprehensively as well-known as high-risk transportation mode.

The objective of this study is to determine the water impact of the proposed design of the seaplane floats in water surface when on the landing phase. Therefore, in this study, we demonstrate seaplane float water-entry problem and landing on calm water and waves that offers more accurate and realistic results for Fluid Structure Interaction (FSI) to generate water impact phenomena between water surface and seaplane float using SPH as Kawamura *et al*., [13] and González-Cao *et al*., [14]. The accuracy of this computational model has been verified to calculate and evaluate various problems. In this study, DualSPHysics as Crespo *et al*., [15] based on SPH, was employed. By determining the interaction between float and water, including pressure and splashed water, the risk of severe conditions might be expected to be predicted. We show that the computational results could turn into valuable inputs for designing future seaplane floats in Indonesia.

2. Numerical Methodology

2.1 Overview of SPH

In this study, we employed DualSPHysics based on SPH. The SPH method is discretized by Lagrangian particles for the Navier-Stokes equations to describe FSI between water and solid. The incompressible Navier-Stokes are implemented locally in each particle location, according to physical properties of neighboring particles when running the fluid dynamics simulation. The surrounding particles is defined by a distance function and each particle has new value of the physical properties that is calculated in timestep transition. The main formulation of SPH is expressed as function $F(r)$ as a physical quantity, which is defined in r' by integral interpolation. In this study, we used the quintic Wendland kernel function, *W*. The pressure was explicitly computed using the equation of state related to the density. Therefore, the computational cost can be reduced compared to the implicit solver using Poisson's equation for pressure. The more detailed information can be found in Crespo *et al*., [15].

2.2 Validation

In this study, the computational model was firstly validated with the experimental work of Iafrati *et al.,* [16]. In this experiment, the flat plate model was used to investigate impact pressure, cavitation, and ventilation modalities. The plate model was set to be the length 1 m, the width 0.5 m, and the thickness 15 mm, respectively. The initial pitch angles to the water surface were 4 and 10 degrees. The horizontal velocity of the flat plate was 40 m/s and the vertical velocity was 1.5 m/s. The particle size is 0.01 m and the number of particles is 27 million. The time increment is 10^{-4} sec. Figure 4 shows the snapshots of water landing phenomenon with splashing of the flat plate. The nonlinear FSI between the flat plate and the free surface with splashing and droplets can be found. Figure 5 shows the comparison of maximum and steady pressure between the experimental results and the computational ones. The tendency of the pressure is acceptable between them, and the maximum and steady pressure values are overall agreement with the experimental results.

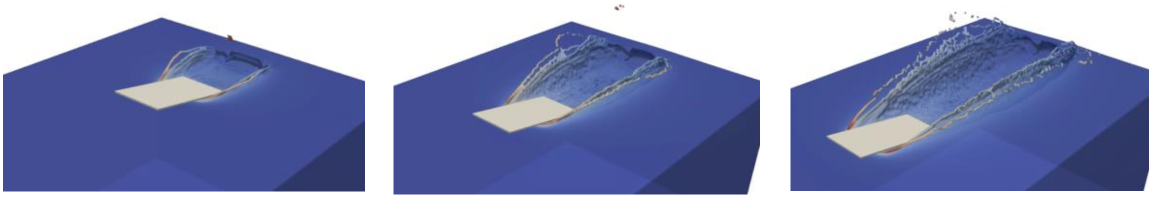
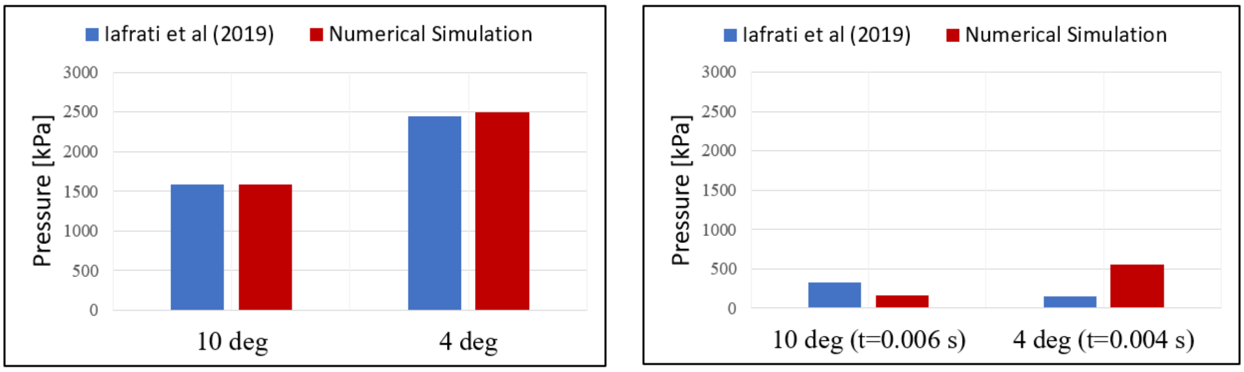


Fig. 4. Snapshots of water landing phenomenon of the flat plate on the calm water

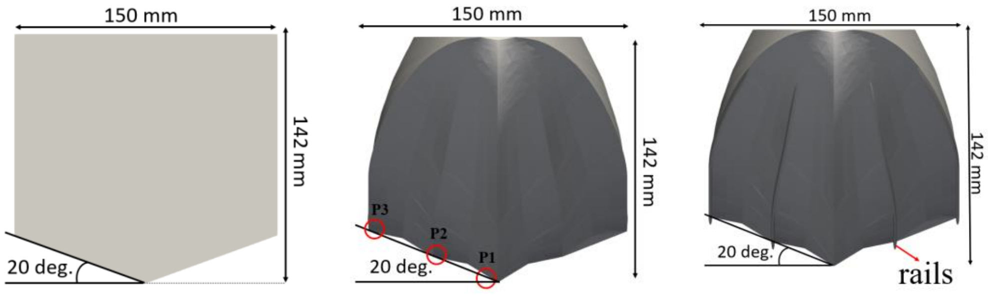


(a) (b)

Fig. 5. Comparison of maximum pressure and steady pressure between present result and experimental result at pitch angle 10 and 4 degrees, (a) Maximum pressure, (b) Steady pressure

2.3 Applications to Seaplane Floater

In this study, the seaplane float was simulated in 2D and 3D cases in the model scale 1:10. The geometry of the 2D models and the pressure measurement points that were located at P1, P2, and P3 during water-entry process as shown in Figure 6. The width of the models is 150 mm, height is equal to 142 mm, and general deadrise angle is 20°. Basically, the wedge model with the flat bottom surface was also computed as a referenced model because it is widely used in various studies of water entry problem. On the other hand, Model (a) and Model (b) were designed with two-stage flares. They are expected to suppress and reduce the pressure distribution during the interaction hypothetically. Specifically, Model (b) have the “rail” parts that could be expected as the water spray controller. The water entry speeds in 2D model are 0.96, 1.28, and 1.6 m/s as in the Froude similarity rule is equal to 4,5, and 6 m/s in real scale. The particle size is 0.001 m and the number of particles is 0.6 million, also the time increment is 0.001 sec. The 3D model is computed as shown in Figure 7 and Figure 8. In general, the seaplane is operated as the actual condition consist of landing, hydroplaning, and take-off. Therefore, the velocity of the seaplane can be divided into three operated stages with horizontal and vertical velocities. The horizontal velocity was set to be 8 m/s and vertical velocity was set as 0.31 m/s in landing and take-off, and 0 m/s in hydroplaning. The pitch angle of the seaplane was set as 9.79 degrees based on Qu *et al.,* [17] which is considered as the optimum angle when ditching for the regional aircraft. The computational domain of the calm water and wave in 3D was set as the depth, length, and width are 2.4 m, 10 m and 6 m, respectively. In the landing wave condition, the heading wave is set to the wave period 1.58 s, the wavelength 3.89 m, and the wave height 0.1 m, respectively in the model scale 1/10. The particle size is 0.02 m and the number of particles is 18.3 million. The time increment is 0.002 sec.



(a) (b) (c)

Fig. 6. Water entry models in 2D with the monitoring points: P1, and P2 and P3, (a) Wedge, (b) Model (a), (c) Model (b)

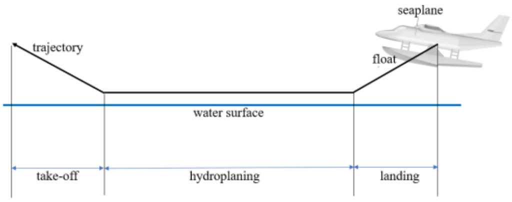


Fig. 7. Trajectory of seaplane landing in 3D

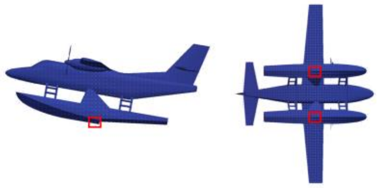
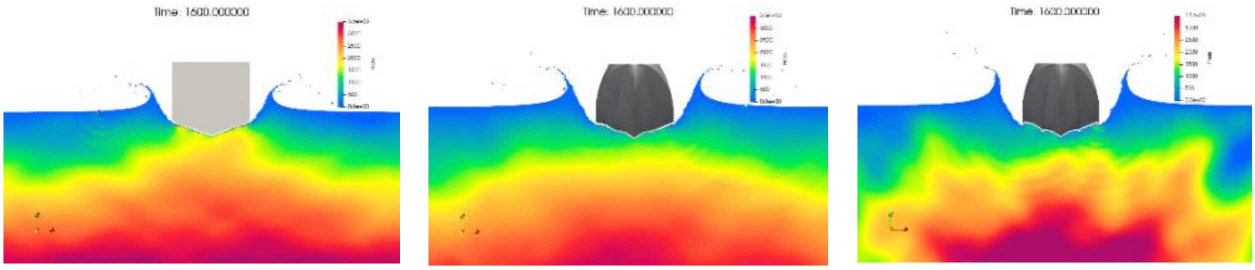


Fig. 8. Bird's eye view of the seaplane

3. Results and Discussion

3.1 Water Entry Problem

Figure 9 shows comparison of pressure distribution during the water entry process in Wedge, Model (a) and Model (b), in which the vertical entry speed of the floater is 0.96 m/s into the water. We can see that the high-pressure region is strongly excited near the bottom surface of the floaters in all cases, then it is expanded and propagated into the deeper depth. The splashing with droplets is rapidly generated from the bottom surface under FSI. We compared time histories of impact pressure at the points: P1, P2 and P3, during the water entry process. We found that the first impact pressure of Model (b) has minimum value compared to that of cases such as Wedge and Model (a) at the points P1 and P2. Then, after $t = 1.5\ s$, the pressure of Model (b) has slightly lower at those measurement positions.

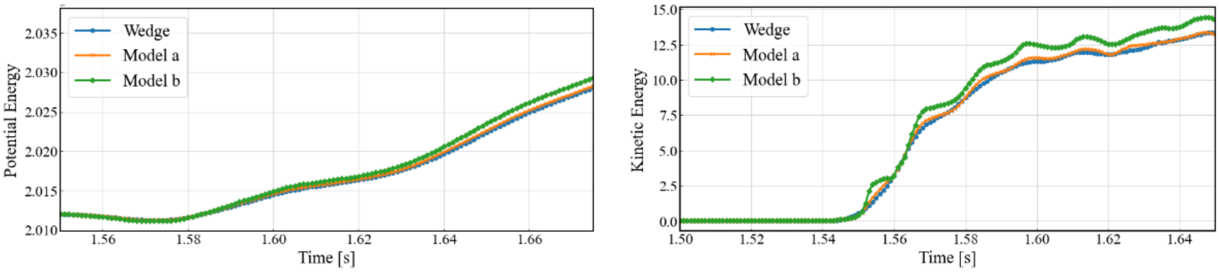


(a) (b) (c)

Fig. 9. Comparison of pressure distribution during the water entry process, (a) Wedge, (b) Model (a), (c) Model (b)

This is because the "rails" as additional parts in Model (b) can reduce the impact pressure and splashing with droplets. On the other hand, the pressure at P3 has different pattern, it means that the highest pressure can be excited in Wedge, and then the lowest pressure can be found in Model (a) at this position.

To quantitatively evaluate attenuation of the fluid energy, the potential and kinetic energy are calculated using the vertical position and velocities at all particles. These energies are expressed as the fluid energy caused by the interaction between the floaters and the water. According to the result as shown in Figure 10, it shows that the tendency of the potential and kinetic energy is comparable, the calculation range which is expanded as the computational domain has caused small disparity value among the models.

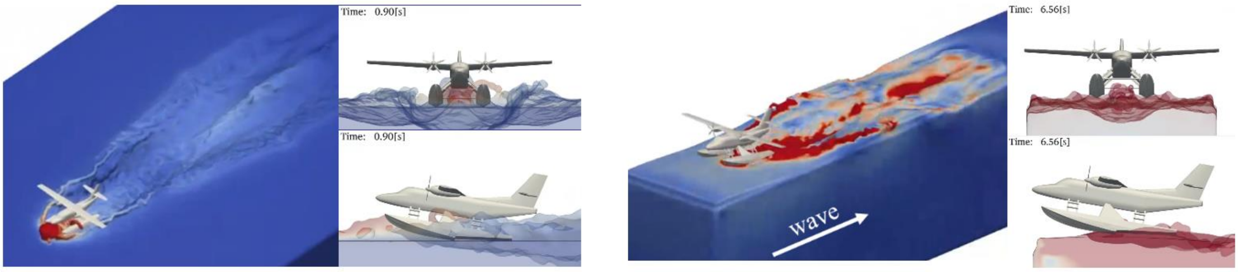


(a) (b)

Fig. 10. Comparison of time histories of (a) potential energy and (b) kinetic energy

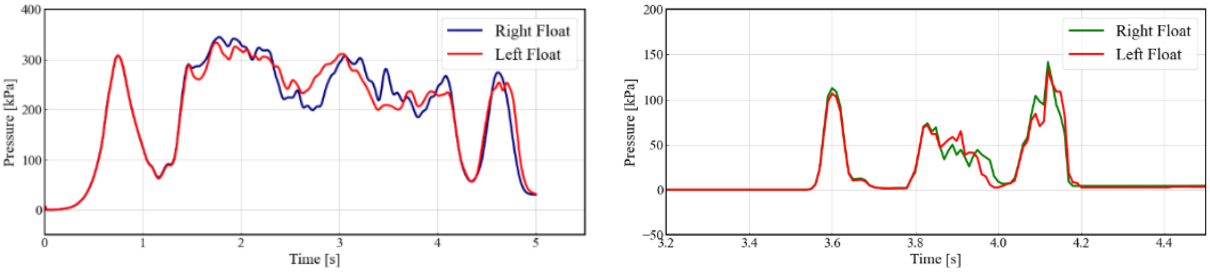
3.2 Landing in Calm Water and Waves

Figure 11 shows the snapshots of seaplane landing on the calm water and waves. The computational conditions are explained in Section 2.3. The impact pressure is monitored on the bottom of the floater indicated by the rectangular red area as shown in Figure 8. We compared time histories of impact pressure acting on the bottom surface of the floats during landing process in the calm water and waves as shown in Figure 12.



(a) (b)

Fig. 11. Snapshots of the velocity distribution around seaplane landing, (a) Landing on the calm water, (b) Landing on the regular waves



(a) (b)

Fig. 12. Comparison of time histories of pressure on the bottom of the floater, (a) Calm water landing process, (b) Wave landing process

The maximum pressure can be found at the second impact and tend to generate steady pressure until the seaplane takes off over 300 kPa. On the other hand, in the landing waves, the seaplane floater hits three periodic waves during the landing process, then the maximum pressure, that is less than 150 kPa, can be generated at the third waves compared with the first and second ones. The maximum pressure in the calm water is different from that in other cases. This is because the influence of the touch-down position of the seaplane floater. In the calm water, the floater is ditching at the water surface continuously, whereas in the landing waves case, the pressure is generated when the seaplane float lands on the waves in the shorter time.

4. Conclusions

This study developed a computational model using Particle Based Method, DualSPHysics based on SPH to develop a seaplane floater, which can reduce impact pressure and splashing with droplets. The developed model can reproduce FSI during water entry and landing process on the calm water and wave. The model could investigate the characteristics of the proposed seaplane float and can reproduce the accurate and realistic results, then it could be also used for the interaction between the seaplane floater and the water surface. Further investigation of the landing waves process in wider range domain and finer particle should be needed, and the model validation should be required with experiments as future works.

Acknowledgement

This study was partly supported and funded by Lembaga Pengelola Dana Pendidikan (LPDP) Republic of Indonesia.

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