

Multi-Phase CFD Simulation of Lifeboat Free-Fall Launch Dynamics with Varying Pitch Angles

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Abstract

The objective of this study is to simulate the free-fall launch of a lifeboat and to analyse its trajectory, pitch angle, velocity, acceleration, and pressure dynamics using Open Field Operation and Manipulation (OpenFOAM). Utilising the overset grid technique, which is well-suited for handling the expected large motions, the study employs multi-phase simulations based on the volume of fluid method. A series of 21 simulations is conducted, varying initial pitch angles and three different drop heights to thoroughly examine the lifeboat's behaviour under various conditions. The analysis of pressure across multiple points along the same transversal and longitudinal planes reveals two significant pressure peaks: one at the bow during water entry and another at the stern, occurring after a secondary water entry triggered by turn-back spins due to restoring moments. Pressure contours indicate that the keel experiences the highest loads, highlighting it as a critical area of concern. Additionally, the kinematics of each scenario is analysed to determine which initial pitch angle would allow the lifeboat to distance itself most effectively from potential hazards without additional impulse. This aspect of the study aims to identify optimal launch conditions that enhance safety and minimise risk during emergency deployments.

Keywords CFD simulation; Water entry; Free-fall launch; Lifeboat; Overset mesh

1 Introduction

The safety of life in the sea should be guaranteed for a ship to navigate. One way to secure this during extreme maritime incidents where the crew and persons on board must leave the ship is by having and using lifeboats. This

kind of boat is required to be launched from a ship deck or a platform from a considerable height, gaining enough momentum and saving launch time. In this scenario, the lifeboat experiences a free-fall process before approaching the water surface, entering at high speed, and causing significant pressure forces on the lifeboat structure, if the boat is launched or misdesigned, the structure can be compromised causing severe damage to the hull structure and threaten the personal safety of the crew (Qiu, et al., 2020). Therefore, it is essential to assess the water entry impacts and prepare accordingly during the lifeboat design circles (Huang, et al., 2021).

Investigating the water entry process and the associated hydrodynamic pressures remains a challenge even today, due to the complex physical effects (Wang and Guedes Soares, 2017; Guo et al., 2025). The water-entry process of lifeboats is a fluid–structure interaction problem characterized by complex physics and affected by various factors. (Wang et al., 2024a). The most reliable method for investigating the process is conducting experiments (Wang et al., 2024b; Wang and Guedes Soares, 2025), however the measurement of the pressure distribution is always expensive and challenging. Because the phenomenon is highly nonlinear, pressure transducers need to be both precise and capable of high-frequency response. Measuring the hull pressure accurately would require numerous sen-

Article Highlights

- The free-fall launch process of lifeboats is simulated using the open-source CFD tool OpenFOAM with the overset mesh technique.
- Various free-fall heights and pitch angles are examined to predict both the slamming and the trajectory of the lifeboat.
- Peak pressures are primarily concentrated at the bow and the stern, with the stern experiencing higher pressures than the bow in most cases.
- Steeper pitch angles (60°–70°) reduce harmful accelerations, while a 30-meter drop posed consistent risks, highlighting the need to optimise both drop height and angle for safe water entry.
- Results demonstrated that a 70° pitch angle enabled the most effective rapid escape from hazardous zones post-launch, while a 10° angle was the least effective.

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sors across the surface, making the setup unrealistic. Several alternative approaches, such as potential flow-based methods and CFD simulations, are under continuous development and still require validation against existing experimental results.

The water impact pressure variation has been a significant application in naval architecture and offshore structures. The water entry process has been considered as the typical case for evaluating the dynamic pressures during wave impacts. Von Kármán (1929) conducted a pioneering study to estimate the forces acting on a seaplane during water landings. He introduced a method that calculates the hydrodynamic force on a bluff body entering a liquid surface by considering changes in momentum. Wagner (1932) developed a theoretical model for the idealized problem of a two-dimensional wedge entering water, with the assumption of linear boundary conditions, while neglecting gravitational effects (Huang, et al., 2021; Shen, et al., 2016). This approach has been widely employed to predict water-entry loads and to couple with finite element methods for structural analysis. However, it still overlooks certain hydrodynamic effects, which can lead to an unrealistic representation of the flow field. For instance, phenomena such as flow separation, which commonly occurs around wedge-shaped bodies, are not captured by the model. Based on Wagner's asymptotic solution, other researchers have made changes and adaptations to apply it for practical conditions.

Based on the panel method, a numerical method for investigating water entry of a two-dimensional body with an arbitrary section, was proposed by Zhao and Faltinsen (1993). Although this method agrees well with experiments and has been still widely used, it neglects the effects of gravity, which limits its application to the water entry process. To solve this problem, this method was then extended by Sun and Faltinsen (2007), while Wu et al. (2010) included the nonlinear velocity potential flow theory. During the water entry phase of a lifeboat, hydrodynamic forces were calculated using the strip method in Qiu et al. (2023). However, these solutions did not account for viscous effects and are mostly applied for 2D sections or 3D cases with a simple geometry.

In recent years, Computational Fluid Dynamics (CFD) applications that aim to solve the Navier-Stokes equations numerically have become more widely used and developed. CFD has been extensively used to estimate fluid flow and wave-induced loads on structures, and motions. It has demonstrated high accuracy in analyzing hydrodynamic problems involving interactions between solid bodies and multiphase flows with free surfaces, as well as in addressing hydroelasticity problems (Tavakoli et al., 2023; Hosseinzadeh et al., 2023; Chen et al., 2023). In addition, Smoothed Particle Hydrodynamics (SPH) algorithms have been utilized to investigate the water entry problems as well (Huang et al., 2022; Lyu et al., 2022).

In particular, the open-source CFD library Open-FOAM has been widely used in slamming problems. Wang and Guedes Soares (2020) and Wang et al. (2021) have studied the effects of compressibility, three dimensionalities and air cavity on a free-falling wedge cylinder, where the three scenarios are simulated using the Reynolds-Average Navier-Stokes (RANS) equations and volume of fluid (VOF) in OpenFOAM library, and the results are compared to the available experimental data. Shen et al. (2016) used both OpenFOAM and star-CCM+ to simulate 2D sections and 3D models of a 10K container ship, where it stated that the dynamic overset grid technique in OpenFOAM had demonstrated its flexibility and efficiency for large amplitude motions, which is suitable for slamming problems (Shen, et al., 2016).

Regarding the specific study of pressure loads on a lifesaving boat, MARINTEK (Kauczynski et al., 2009) has conducted over 25 000 tests with 14 different lifeboats dropped from a skid or vertically. These tests were particularly important for validating the several numerical models and simulations that were eventually studied. Ringsberg et al. (2017) presented a benchmark study to demonstrate the practical use of quasi-response methods for the assessment of impact loads on modern FFLBs, where eight different calculation methods were compared based on analytical plate strip models (linear and nonlinear idealisations), and FE models of different configurations and complexity (quasi-static linear, GNL, linear-elastic and transient dynamic). Qiu et al. (2020) have established a mathematical model using the strip theory and Kane's method, where the FFLB motion is calculated from the beginning of the skid until water entry and is compared to the star-CCM+ simulation results. Huang et al. (2021) developed a model based on CFD to simulate and analyse the water entry process holistically, applying the overset mesh technique, comparing it with experimental data and studying the influence of changing the dropping height and inclined angle.

The objective of this study is to simulate slamming problems in OpenFOAM, specifically the entire process of a lifeboat's free fall, and investigate the trajectory, pitch angle, velocity, acceleration, and pressures of the boat.

2 Numerical method

OpenFOAM (Open Field Operation and Manipulation) is an open-source software toolbox designed for developing customized numerical solvers, as well as pre- and post-processing utilities, for solving continuum mechanics problems.

In this study, a multiphase simulation using the VOF (Volume of Fluid) method is performed to model two immiscible fluids. The overInterDyMFoam solver in OpenFOAM, which supports VOF and overset meshes, is employed along with the Chimera meshing technique to

handle large-amplitude motions typical of slamming events. The model solves a single set of momentum equations while tracking the volume fraction of each fluid in every computational cell.

The governing equations are presented below (Albadawi et al., 2013):

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{V}) = 0 \quad (1)$$

$$\frac{\partial (\rho \mathbf{V})}{\partial t} + \nabla \cdot (\rho \mathbf{V} \mathbf{V}) = -\nabla P + \nabla \cdot \boldsymbol{\tau} + \rho \mathbf{g} + \mathbf{F}_\sigma \quad (2)$$

$$\frac{\partial \alpha}{\partial t} + \nabla \cdot (\alpha \mathbf{V}) + \nabla \cdot (\mathbf{V}_c \alpha (1 - \alpha)) = 0 \quad (3)$$

where ρ is the fluid density, $\mathbf{V}$ is the fluid velocity vector, $\boldsymbol{\tau}$ the viscous stress tensor defined as $\boldsymbol{\tau} = 2\mu \mathbf{S} = 2\mu (0.5[(\nabla \mathbf{V}) + (\nabla \mathbf{V})^T])$, μ the fluid dynamic viscosity, P the scalar pressure, $\mathbf{F}_\sigma$ the volumetric surface tension force, $\mathbf{g}$ the gravitational acceleration vector, $\nabla \cdot (\mathbf{V}_c \alpha (1 - \alpha))$ an anti-diffusion heuristic term and α the interface capturing.

In this study, the structure is modelled as a free rigid body, with gravity and surface forces (pressure and shear stress) included (Benites-Munoz et al., 2020). At each time step, the six DoF solvers integrate pressure and viscous stress components over the wetted surface to compute resultant forces and moments about the center of gravity. The accelerations are obtained by dividing both resultants by their respective inertia terms, and they can be integrated into velocity and displacement using the Newmark integration with $\gamma = 0.5$ and $\beta = 0.25$.

The simulation employs the overset (Chimera) mesh framework in OpenFOAM, creating independent background and overset meshes to handle mesh motion. It avoids the problems and instabilities associated with deforming meshes (Tisovska, 2019).

3 Lifeboat CFD simulation

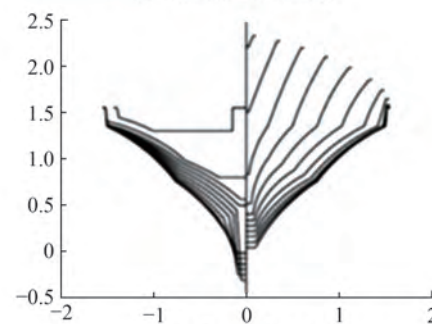
To evaluate the capability of predicting the loads and the vessel's motion, a case study is performed by using a model of a free-fall lifeboat with a dropping height H and a pitch angle α . This model is a recreation based on the Schat Harding 1000, used by researchers (Ringsberg et al., 2017; Huang et al., 2021) who compared the numerical calculation with the experimental study conducted on a full-scale model (Kauczynski et al., 2009).

For this study, however, it was not possible to use the same model due to copyright matters. Even so, the geometry could be reproduced by using the body plan from Figure 1 and the side view of the ship in Rhinoceros from Figure 2. The lifeboat's main particulars are also shown in Table 1.

The result of this reproduction is shown in Figure 3. Distortions of shape and dimensions of about 5.4% have occurred in the process.



(a) Lifeboat skid setup



(b) Lifeboat's body plan

Figure 1 Lifeboat model in the study (Ringsberg, et al., 2017)

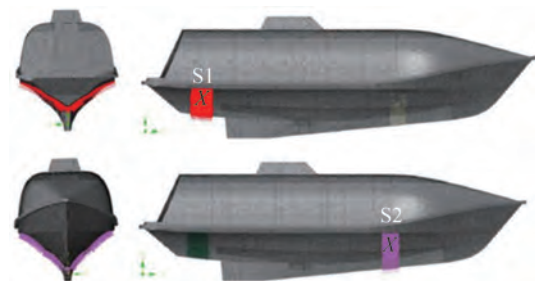


Figure 2 Front and side view of the lifeboat (Ringsberg, et al., 2017)

Table 1 Main particulars of the full-scale lifeboat (Ringsberg, et al., 2017)

Parameter	Value
Overall length (m)	12.57
Overall width (m)	3.34
Displacement (ton)	16.8
LCG forward of stern (m)	5.29
Radius of gyration in pitch (% of LOA)	25%

The computational domains are shown in Figure 4, and the overset domain dimensions are shown in Figure 5. Various dropping heights of 10 m, 20 m, and 30 m are simu-

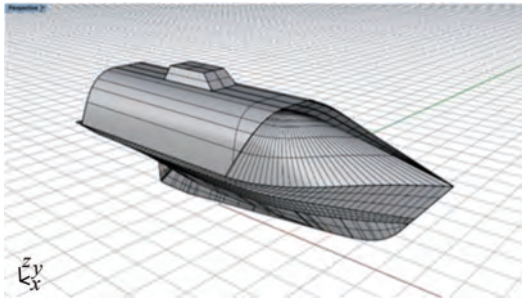


Figure 3 Reproduction of the lifeboat hull surface in Rhinoceros

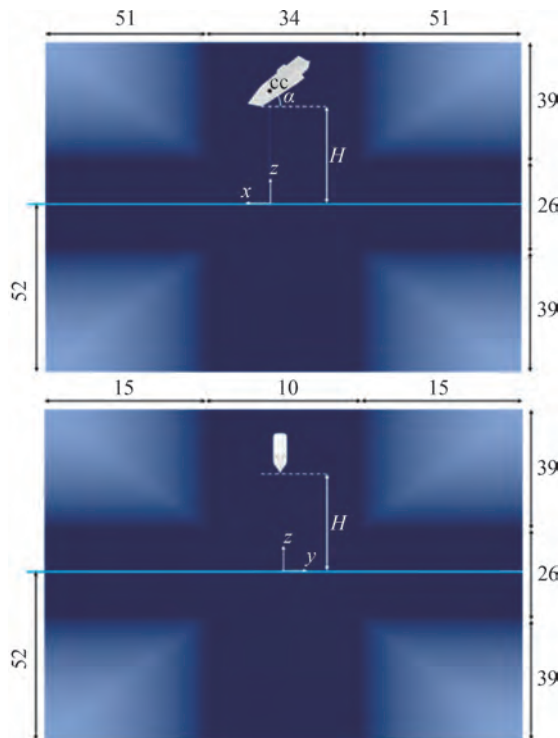


Figure 4 Views of the background domain for the lifeboat. Dimensions in meters

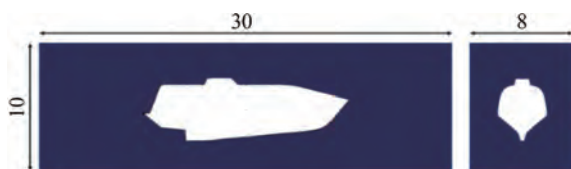


Figure 5 Dimensions of the overset domain in meters

lated, with falling angles ranging from 10° to 70° in 10° increments, totalling 21 simulations. The scenario, axis convention and the cell concentration division are illustrated in Figure 4. The origin is set to be on the waterline, with coordinates (x, y) equal to the centre of gravity. The cells are chosen to have about 40 cm in the water entry region and Chimaera. The simulation is set as laminar and the time step used is 10–3 s. To capture sufficient details for a water entry problem, the Courant number is set to always be smaller than 0.3, based on the analysis of Muzaferija (1999).

4 Results and discussion

An overview of the general simulation is given with comments and considerations. Regarding the mesh and computational effort, an Intel Core i9-4570@3.2 GHz with 126 GB of RAM and 27 processors was used. The general overview of the simulations' parameters is shown in Table 2.

Table 2 Summary of the simulations

Parameter	Value
Background cells	1 141 292
Overset cells	36 292
Minimum cells (cm)	40
Time (h)	About 4 h

For the case of the overset, which has the snapping process, the result can be seen in Figure 6. The process resulted in a shape similar to the designed lifeboat but with some deviations due to the snapping process. This alteration is expected for coarse meshes where the refinement of the snapping process is not enough to acquire all the information, which is the result of the choice to have faster and more stable simulations where the whole lifeboat journey can be described.

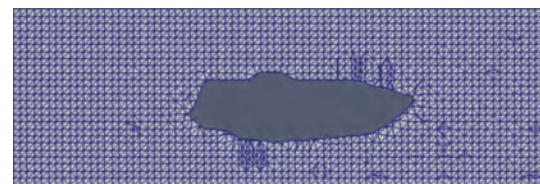


Figure 6 Side view of the overset mesh with the lifeboat's external surface

To capture the pressures on the hull bottom, the intersection between the hull and three planes is considered as shown in Figure 7. The transversal planes in the bow and stern are divided into 11 points over the impact surface (hull below) where the pressures are taken, while for the longitudinal plane, 21 points are considered, as shown in Figure 8.

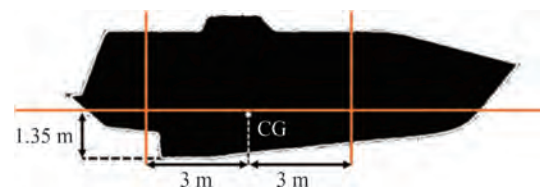


Figure 7 Planes for pressure study

Regarding the pressures on the stern plan at the same height and different pressures, as shown in Figure 9, they generally exhibit the same behaviour with varying peak val-

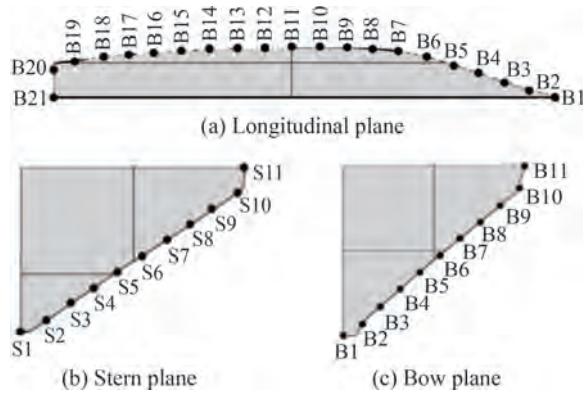


Figure 8 Locations of the probes sensors.

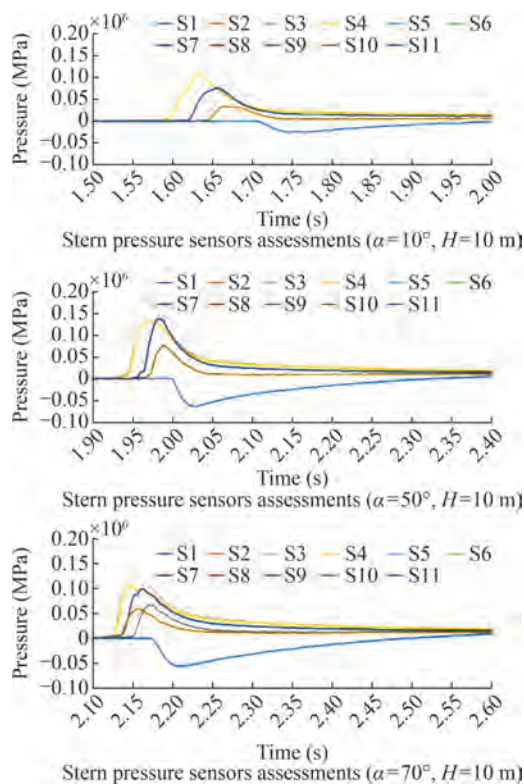


Figure 9 Time series of stern pressures for dropping height of 10 m

ues. Some simulation results are the same because the space between control points is insufficient to occupy different cells with distinct properties and parameters. The highest peak is formed by the three lowest points on the keel, while the highest one at S11 has negative pressure due to water jet detachment at this point. In general, the higher the point, the lower the pressure will be, except in 50° where S5, S6 and S7 were lower than S4. The angle with the highest pressure was 50°, which already can indicate which scenario would have larger impact loads.

The same analysis can be performed for the selected bow plane, as in Figure 10. They are considerably lower than the stern entry, indicating that the rotation during water entry can provoke another slamming itself on the back of

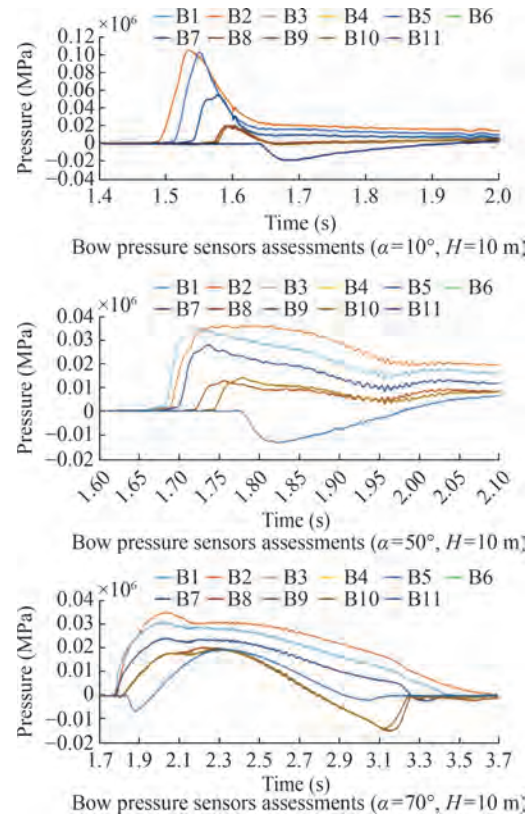


Figure 10 Time series of bow pressures for dropping height of 10 m

the hull. They have different shapes even if they have peaks, especially in the case of 70° compared to the rest. As for the behaviours, similarly, the bottom control points are usually the highest peaks, where the first two compete for the highest, while the less critical one is the highest one on the boat due to water detachment. It results in larger peak bells and is a demanding region, especially in what concerns forward velocity. The summarised results of the assessment of the longitudinal planes are shown in Figure 11. Usually, there are two highlighted peaks, one for L1, which means the forward border, and another one for the other in the middle before ending the simulation, except for the 10° launch, which also has to do with the way the boat dives. What is also notable is that the one with a higher peak is also from 50°.

In Figure 12 the comparison is not between angles, but dropping heights, and all abscises were set to start at the free-fall time, which is $t = \sqrt{2H/g}$. The B sensor is referred to as B2, while S stands for S3. Notably, the behaviour of the pressure curves is mostly the same for different heights, with the difference in the pressure peak being strongly influenced by the gained velocity from free fall. They differ not only by the peak value at the top but also by the decay velocity, which becomes faster as it starts from a higher value. The peaks also get closer to each other for greater heights due to this same relation: the faster

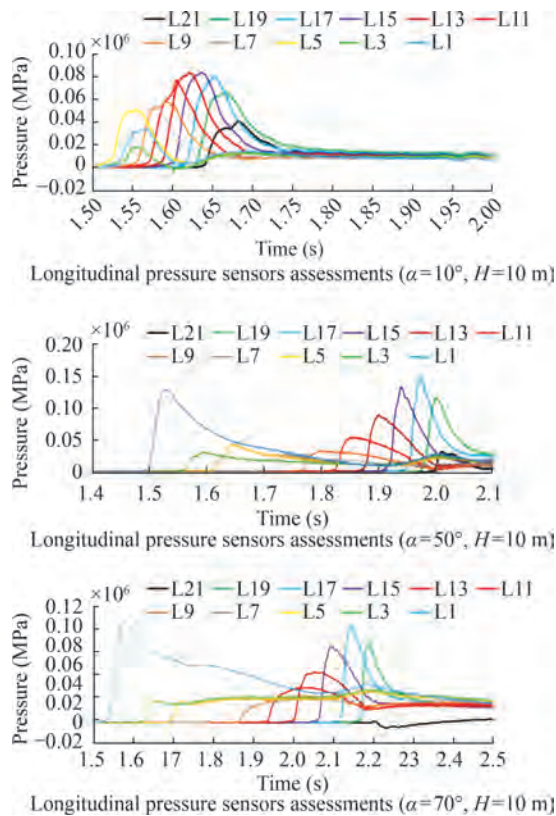


Figure 11 Time series of longitudinal pressures for dropping height of 10 m

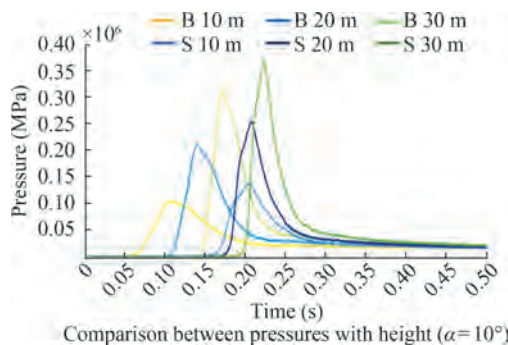


Figure 12 Comparison of pressure for different heights and $\alpha = 10^\circ$

velocity that the lifeboat acquires reduces the time in which the event occurs.

When using probes, it is possible to observe how pressure behaves over time at a specific point, but it is not possible to analyse what happens to the entire surface. Figures 13 to 15 show the contour plots of pressure for 10° , 50° , and 70° angles, starting from 1.6 s when the lifeboat begins entering the water. It is limited to the output interval previously defined and also to the computer's memory, but it has the advantage of mapping pressure over the entire surface and even indicating where the pressure sensors should be placed in the next simulation. The first two time instants considered are the most critical for the lifeboat, where the high-

est peaks appear due to the water entry. After this, the pressure decays until further stabilisation at a lower value. What is noticeable in all simulations is that the keel is the boat element where the pressure peaks concentrate, which is expected since there is an impact region with the water at high speed.

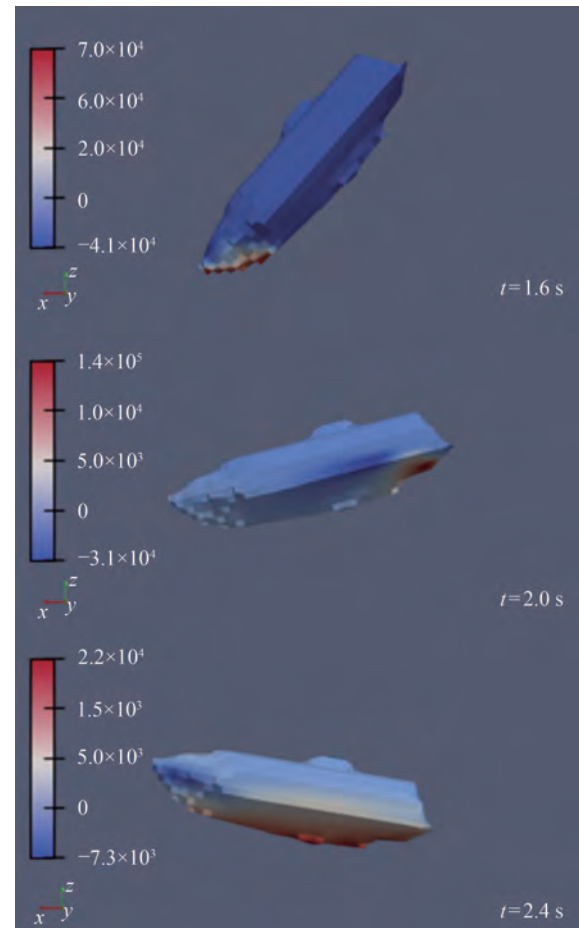


Figure 13 Pressure contour plot for $\alpha = 70^\circ$. Units in Pa

Two regions are of interest where the peak loads concentrate: the bow deck and the stern. The bow is the first to enter and receive the highest loads due to the impact of calm waters. After this, the turn-back that the ship suffers due to the restorative moment provided by the water buoyancy causes the stern to also hit the water, creating another slamming impact, one with ever higher peaks than the bow. This does not happen with the 70° scenario because, in this case, the lifeboat dives before undergoing the turn-back rotation, and the peak for diving is lower than for hitting.

In this part, the general kinematics of each simulation is discussed. The simulations have planar motion instead of unidirectional, as was the case with the wedges in Chapter 3. This type of assessment also holds importance beyond the impact loads, given the significance of how the lifeboat will respond when required in an emergency. In general, it

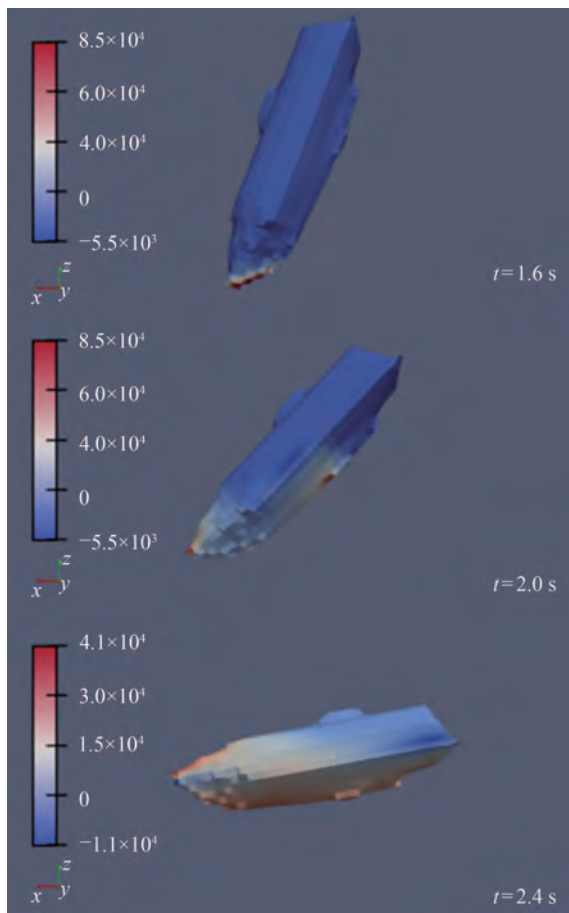


Figure 14 Pressure contour plot for $\alpha = 50^\circ$. Units in Pa

should get as far away from the hazardous event as possible when launched, and its journey should not harm or injure the people on board.

Firstly, what can be analysed is the acceleration in each direction in Figure 16. The horizontal acceleration in this type of study is important because it provides the initial velocity that enables the vessel to move forward from the dangerous zone. What is first noted is that the higher the dropping height is, the higher the acceleration gets. The peaks can give an idea of which cases the boats would not go far, being the ones with the smallest peak because they would not acquire much initial horizontal velocity. Similarly, this analysis can be extended to the vertical acceleration, shown in Figure 17. The behaviour is similar to what is seen for the horizontal acceleration, there is a positive peak before a negative one, expected for floating dynamic structures. The peaks seem to be larger, which has most to do with how long it takes to override and invert the vertical velocity and the trajectory of the water. The free-fall stage is marked by the constant acceleration of g for vertical acceleration and close to 0 for horizontal. Also, regarding the dropping heights, what is remarkable is that the greater the height, the greater the acceleration peak, which is expected because the higher the boat falls, the higher the

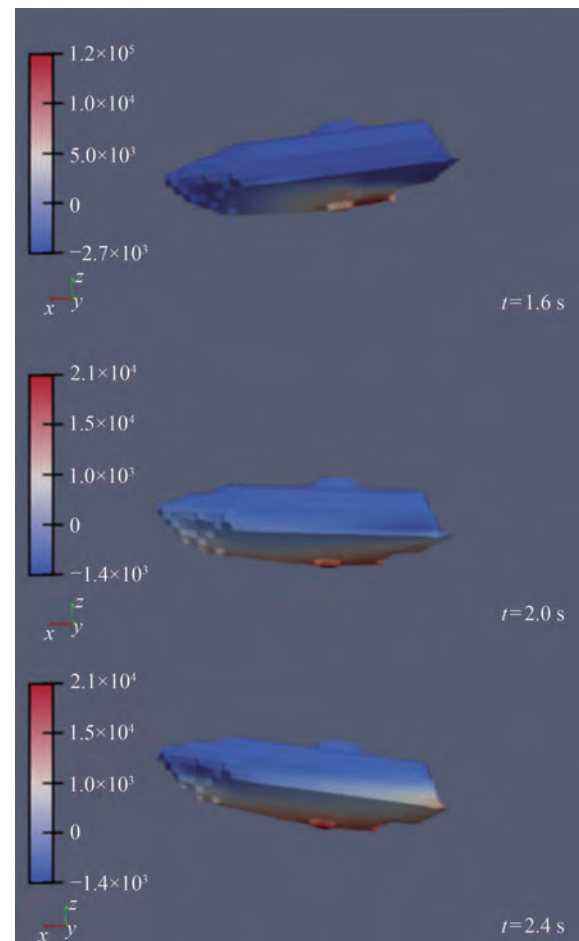


Figure 15 Pressure contour plot for $\alpha = 10^\circ$. Units in Pa

velocity before hitting the water which should be nullified.

Acceleration is an important factor to consider when dealing with watercraft, lifeboats especially, because exaggerated acceleration can increase the probability of injuries on board, and depending on the acceleration intensity, it can be even fatal to humans (Pearce, 2020). One way to assess if the case's accelerations are adequate is to use the IMO Combined Acceleration Response (CAR), shown in (Netherlands Regulatory Framework-Maritime, 1993), where the Square Root Sum of the Squares (SRSS) acceleration should not surpass the ellipsoid with axis of $15g$'s in the $\pm x$ axis and $7g$'s in an-other axis, as shown in Equation (4).

$$CAR_i = \sqrt{\left(\frac{a_{x_i}}{15g}\right)^2 + \left(\frac{a_{y_i}}{7g}\right)^2 + \left(\frac{a_{z_i}}{7g}\right)^2} \quad (4)$$

To assess which simulated cases could be dangerous for people, the seats are assumed 90° and front-facing. Additional centripetal and tangential accelerations due to rotation are neglected, which is reasonable for small crafts, and in this case, the chairs' angles and positions are unknown. In this case, the conversion of acceleration from

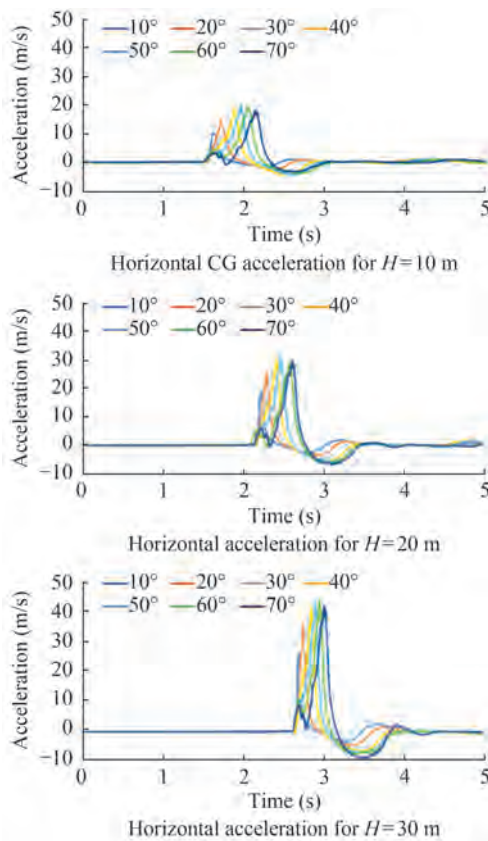


Figure 16 Lifeboat's horizontal acceleration time series

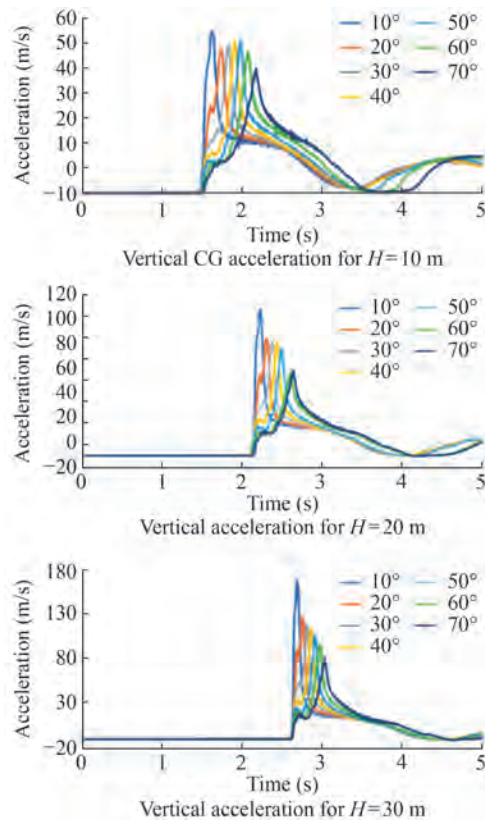


Figure 17 Lifeboat's vertical acceleration time series

the global cartesian coordinates to the seat relative coordinate can be done by rotation matrix transformation. Table 3 contains the results for the maximum CAR obtained with these premises. What is seen is that for greater heights and lower angles, the acceleration can be problematic and risky for the fleeing crew and passengers. This does not mean that people will get injured in these other cases, but the probability of human injuries is greater (IMO, 1991).

Table 3 Maximum CAR for each simulation

Values (m)	10°	20°	30°	40°	50°	60°	70°
10	0.81	0.72	0.74	0.78	0.79	0.73	0.63
20	1.60	1.29	1.25	1.25	1.21	0.92	0.96
30 m	2.45	1.90	1.84	1.73	1.73	1.53	1.31

Another kinematic parameter that can be analysed is the velocity. This measure has less to do with how smooth or hard will the lifeboat enter the water, but more related to how the kinetic energy gained with the free-fall is converted. Ideally, the falling velocity should be turned integrally into forward velocity, but this is not what happens, since there is a loss of energy to waves, viscosity and even for heave oscillating. The horizontal velocity plots are shown in Figure 18. In these plots, a peak is followed by a positive forward velocity, with some variation. As previously analysed, the lifeboats with smaller horizontal acceleration peaks ended up with smaller peak velocities and stabilised at a lower velocity, which is not suitable for fleeing a hazardous event. In contrast, those with greater peaks achieved the highest velocity, depending on the angle and height. In this case, 60° is shown to be more efficient for lower heights, while 70° is for higher. As for the vertical velocity, shown in Figure 19, the initial tendency is linear with a constant rate of g , as seen before with the acceleration. After the free-fall stage, it oscillates around zero, which is the tendency to continue until this dissipates into waves, mostly. It is also remarkable that, even with different initial velocities, the first positive peak immediately after entering the water was consistently close to 5 m/s or below.

One aspect to notice not only in the velocities' plots but also slightly in accelerations is that 60° and 70° had a distinct behaviour compared to the rest, not as an outlier from the rest, but because their water entry occurs differently from the others. The reason is due to the lowest point that enters the fluid first. For angles below approximately 50°, the bow part of the keel is the first to touch, while for angles above this angle, it is the bow deck, as illustrated in Figure 20. The change in the keel's curvature affects how the boat is pushed, and it even suffers from a brake right when the slope changes. This explains why the horizontal acceleration has two peaks and why the velocity peaks are a little delayed.

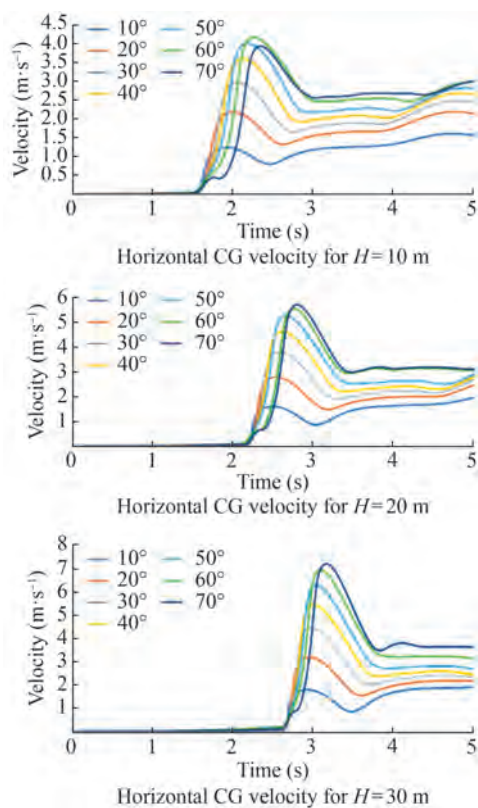


Figure 18 Lifeboat's centre of mass horizontal velocity time series

It is possible to integrate the velocity over time and obtain the offset from the initial position. This effectively demonstrates which scenario, within a 5-second interval, would travel further when dropped from a certain height, as shown in Figure 21. During this interval, the best options that could be further developed were the 60° for smaller heights and 70° for larger heights. If the interval is smaller, the other boats would be more suitable due to the delay in the velocity peak caused by the angle of water entry; however, even so, the higher peak and stabilisation at a higher velocity make them displace further. As for the vertical offset, it presented what was expected from the vertical velocity part. Initially, during the free-fall stage, the time series is parabolic due to the constant gravity. When the boat enters the water, it starts to oscillate freely, with a reduced amplitude due to the loss of energy.

Since all simulations were performed to have 5 seconds, it is possible to notice at what point the lifeboat is when $t = 5$ s, which is when its trajectory is “interrupted”. Besides the stabilisation that the ship starts by damped oscillations after water entry, the greater angles have a longer first valley when entering the water due to the pitch rotation that the vessel suffers when reaching the equilibrium angle after a large amplitude is given. This also has to do with the submergence that the ship goes through at these particular high angles.

Figure 22 shows the trajectory after water entry of the

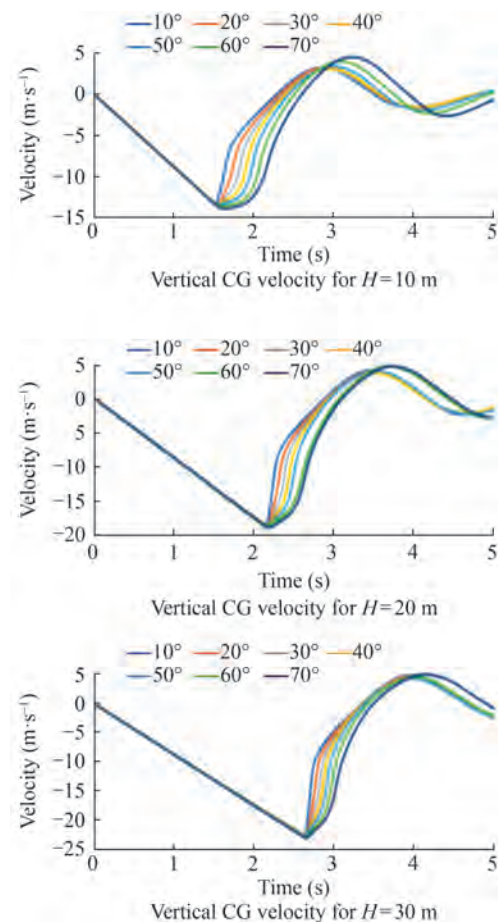


Figure 19 Lifeboat's centre of mass vertical velocity time series

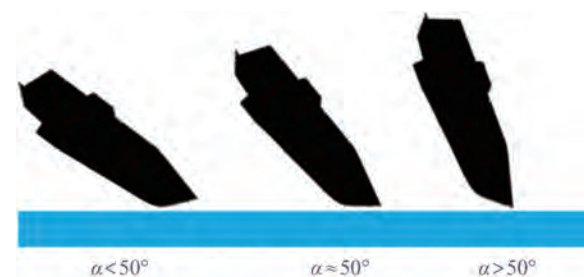


Figure 20 Possible lifeboat entry depending on the angle

lifeboat with different dropping heights ($H = 10$ m, 20 m and 30 m) for the case with a pitch angle of 70°. The changes in the trajectory with different heights did not bring considerable differences, as did the other parameters, except for the diving part or the number of oscillations. From one point of view, this can mean that changing the height did not bring a much faster response to leave the hazardous event. On the other hand, the analysis would be different if the free-falling time was not considered. If removed and just considering the water entry part, these 5 s simulations turn into 2.38 s limited by the 30 m drop height case, and the difference in treatment can be seen in Figure 22.

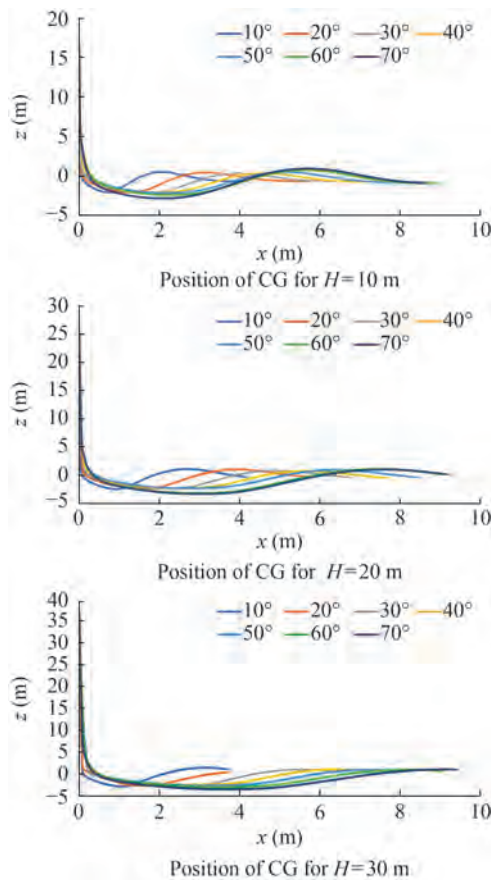


Figure 21 Centre of gravity trajectory over time

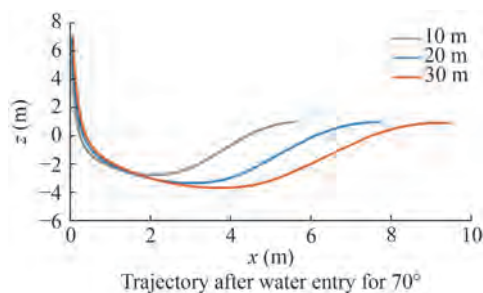


Figure 22 Position of CG during water entry with $\alpha = 70^\circ$

The information on the CG position over time and pitch motion can reveal the motion of the lifeboat throughout its entire journey. Furthermore, OpenFOAM stores the parameter α for the entire domain at each time step set for output. This mapping can also be plotted using paraView, in particular by removing the cells considered holes and slicing them in the middle of the longitudinal plan. The results of this simulation can be seen in Figures 23 to 25, where only the angles of 10° , 50° , and 70° were plotted and displayed. Comparing the water entry of the presented situations, it is notable how the increment of the angle makes the lifeboat more likely to submerge, as seen in Figure 23 to Figure 25, where the lifeboat dives closer to the free sur-

face, while for 70° , the boat already enters almost entirely under the water, which did not occur because it did not have enough velocity to it. For the first two angles, the under-hull mostly hit the water, making the keel absorb most of the impact and converting less energy into actual motion for the lifeboat.

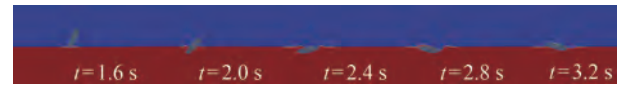


Figure 23 Contour plot of alpha. water for 70° angle



Figure 24 Contour plot of alpha. water for 50° angle

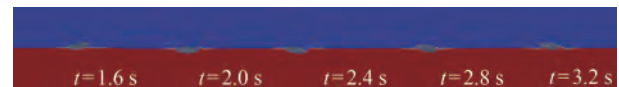


Figure 25 Contour plot of alpha. water for 10° angle

5 Conclusions

In this study, the open-source CFD tool OpenFOAM is utilised, applying the overset mesh technique to simulate the free-fall launch of lifeboats. Various free-fall heights and pitch angles are considered to predict both the slamming pressures experienced during water entry and the trajectory of the lifeboat.

Findings revealed that peak pressures are predominantly concentrated at the bow deck and the stern. The stern experienced higher pressures than the bow in most cases, except under a 70° pitch angle. This suggests that the angle of entry has a significant influence on the impact pressures during submersion.

Kinematic analysis further demonstrated that specific angles, particularly 60° and 70° , resulted in lower probabilities of harmful accelerations. However, a fall from 30 meters consistently posed risks, indicating the importance of optimising drop height and pitch angle to minimise danger. Additionally, simulations assess the lifeboat's capability to move away from hazardous zones after launch without requiring additional propulsion. The results highlighted that a 70° pitch angle was most effective in facilitating a rapid escape, while a 10° angle proved least effective. This underscores the critical role of the submergence phase in the lifeboat's overall performance during emergency evacuations.

In general, the results show that OpenFOAM is a robust tool for addressing slamming problems and the launching process of lifeboats. Further validation and verification analysis are required to assure the accuracy of the simulations.

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