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# Numerical simulation of water-entry problems using an improved multiphase SPH method

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# Outline

# 1. Introduction

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## The water entry of the naval architecture

The ditching of the helicopter


The launching of the ship

**With Smoothed Particle Hydrodynamics Method !**

# 2. Multiphase SPH model

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## 2.1 SPH Equations

**Continuity Equation:**

$$\frac{d\rho_i}{dt} = \rho_i \sum_{j=1}^{N} \boxed{\frac{m_j}{\rho_j}}^{1} \vec{v}_{ij} \cdot \nabla_i W_{ij}$$

**Momentum Equation:**

$$\frac{d\vec{v}_i}{dt} = -\sum_{j=1}^{N} \boxed{\frac{m_j}{\rho_j}}^{1} \left(\frac{p_i + p_j}{\rho_i} + \prod_{ij}\right)\nabla_i W_{ij} + \sum_{j=1}^{N} \boxed{\frac{m_j}{\rho_j}}^{1} \boxed{\left(\frac{\vec{\tau}_i + \vec{\tau}_j}{\rho_i}\right)}^{2} \nabla_i W_{ij} + \vec{g}$$

**Equation of state:**

$$p = \boxed{c^2}^{3}(\rho - \rho_0) + p_b$$

**The weakly compressible SPH method is adopted to simulate the multiphase flow problems*. W is the improved Gaussian kernel function. The 4th order Runge–Kutta integration method and the dummy particle boundary are used in the present work.**

* *Colagrossi A, Landrini M. Numerical Simulation of Interfacial Flows by Smoothed Particle Hydrodynamics[J]. Journal of Computational Physics, 2003, 1*

# 2. Multiphase SPH model

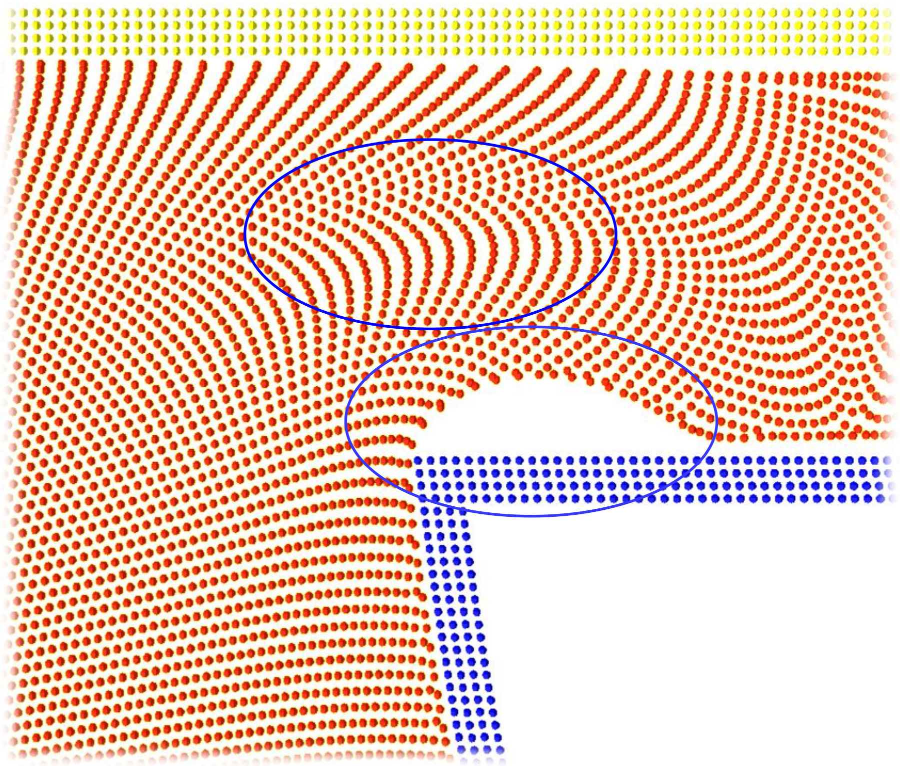
## 2.1 SPH Equations

| | | |
|---|---|---|
| $\frac{m_j}{\rho_j}$ | **The volume information of the *j*th particle is used.** | **Benefit the case:** $\rho_i / \rho_j > 100$ |
| $\frac{\vec{\vec{\tau}}_i + \vec{\vec{\tau}}_j}{\rho_i}$ | **The Larger Eddy Simulation(LES)* is adopted to represent the effect of the turbulence.** | $\mathrm{Re} = Ud/\upsilon_0 > 10^5$ |
| $c$ | **The choice of the sound speed is discussed in the water entry of the body with a small deadrise angle.** | $c_{air} = 340\,\mathrm{m/s}$<br>$c_{water} = ?$ |

*S. Shao, Incompressible SPH simulation of water entry of a free – falling object. International Journal for numerical methods in fluids,59 (2009) 91-115.

# 2. Multiphase SPH model

## 2.2 Multiphase Shifting algorithm



Particle distribution.

**Void and nonuniform distribution?**

$$\vec{r}\,' = \vec{r} + \boxed{\Delta\vec{r}}$$

$$\boxed{\Delta\vec{r}} = A_s h \,|\vec{v}_i|\sum_j \boxed{(C_j - C_i)}\frac{m_j}{\rho_j}\nabla W_{ij}$$

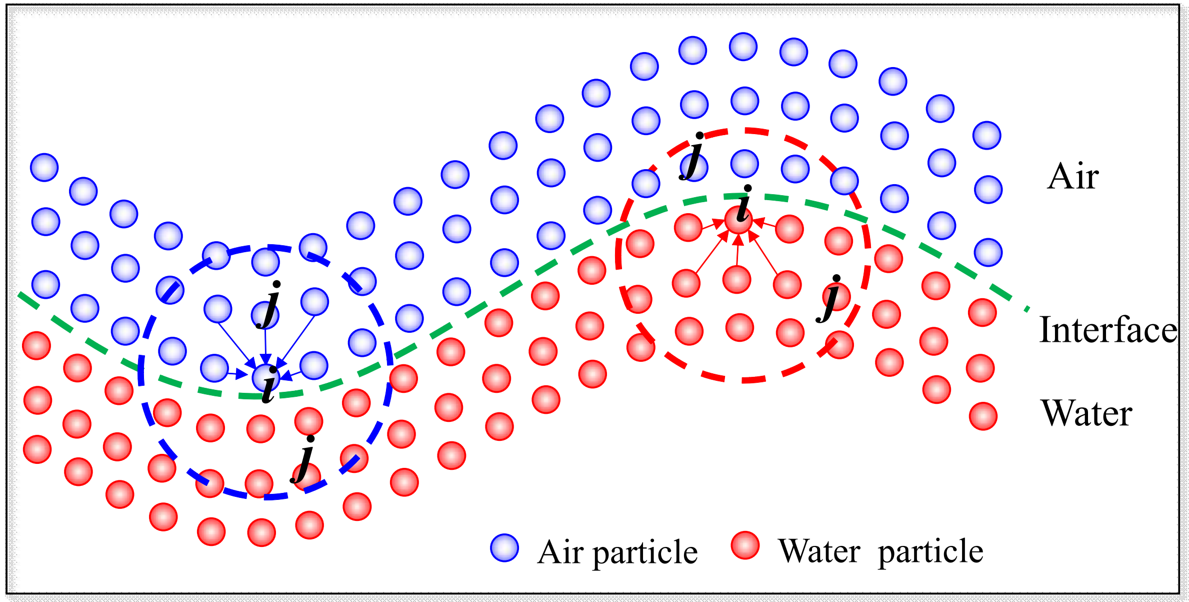
$$\boxed{C_i} = \sum_j \frac{m_j}{\rho_j} W_{ij}$$

**The shifting algorithm* is used within the fluid domain except the particles around the interface to avoid unphysical penetrations.**

*R. Xu, P. Stansby, D. Laurence, Accuracy and stability in incompressible SPH (ISPH) based on the projection method and a new approach. Journal of Computational Physics,228 (2009) 6703-6725.

# 2. Multiphase SPH model

## 2.2 Multiphase Shifting algorithm




The detection of the interface particles.

**The interface particle *i* is detected according to the value *Q* and its neighboring particles.**

$$Q_i = -\sum_j \frac{m_j}{\rho_j}\vec{r}_{ij}\cdot\nabla_i W_{ij}\,(i_{kind} = j_{kind})$$

$$(Q_i < 2)\cap(i_{kind} \neq j_{kind})$$

no

$$\Delta\vec{r} = A_s h\,|\vec{v}_i|\sum_j (C_j - C_i)\frac{m_j}{\rho_j}\nabla W_{ij}$$

yes

$$\Delta\vec{r} = 0$$

# 3. Numerical validation

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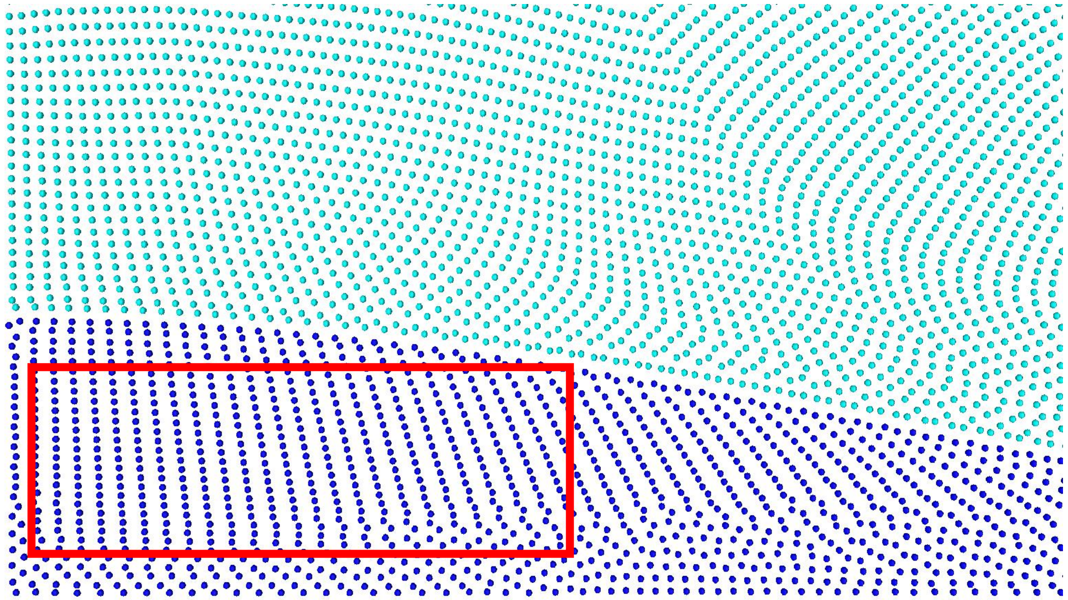
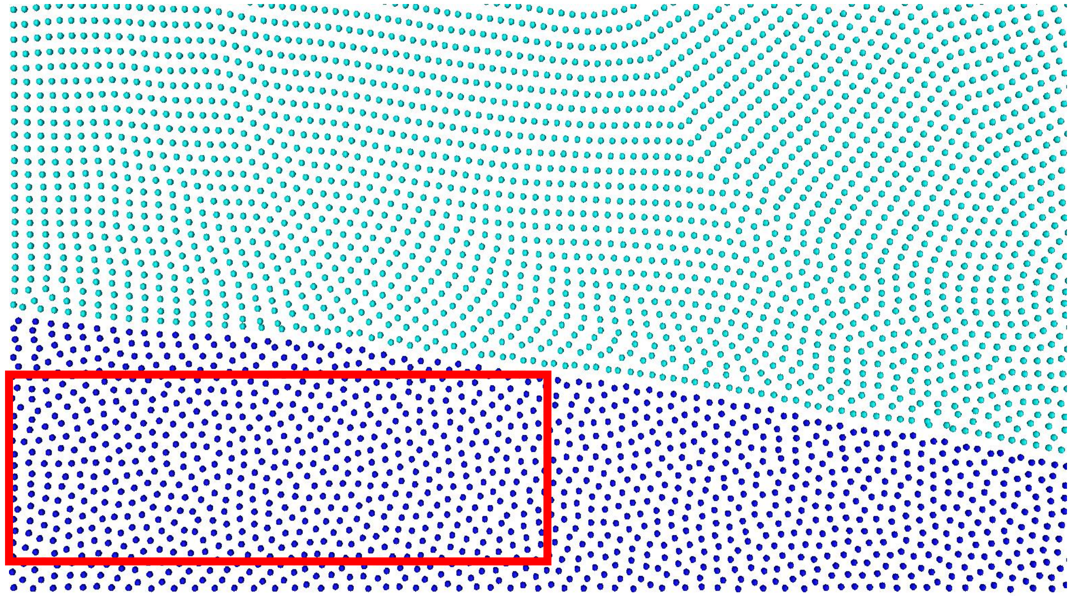
## Dam breaking flow



Without shifting algorithm.

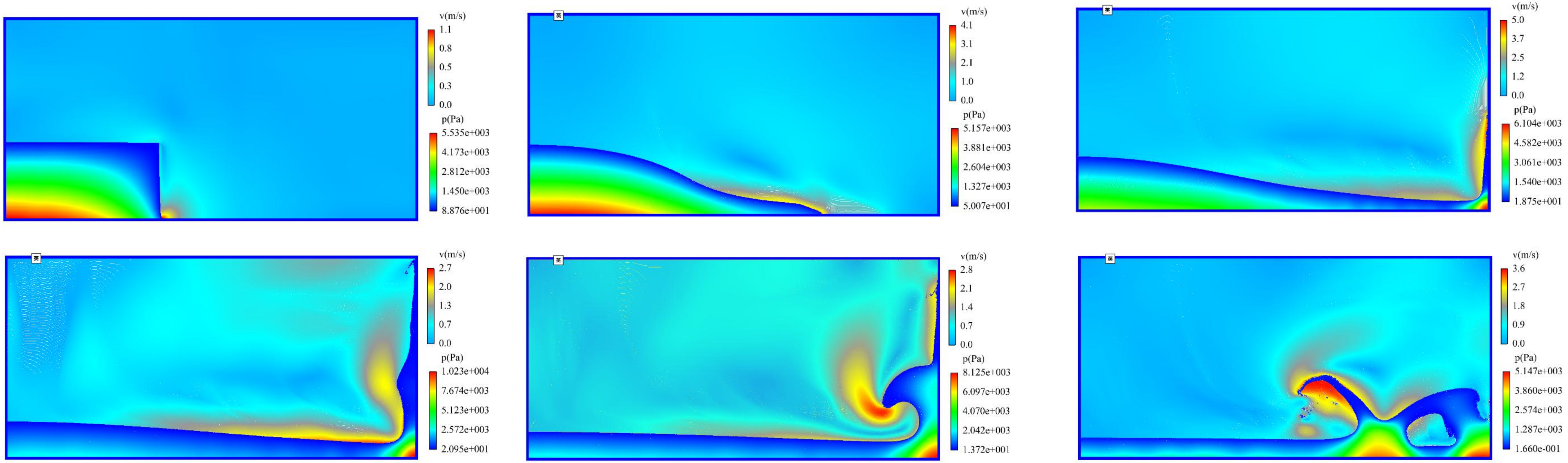


With shifting algorithm.

**The particles especially in water are distributed more uniformly with the shifting algorithm. Besides, the interface is clear which verifies the feasibility of the shifting algorithm model adopted in the paper.**

# 3. Numerical validation

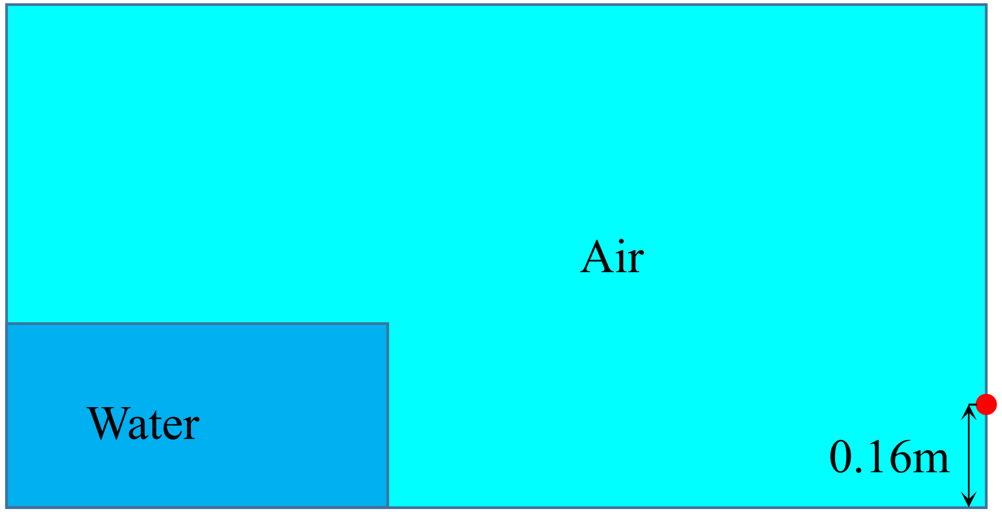
## Dam breaking flow



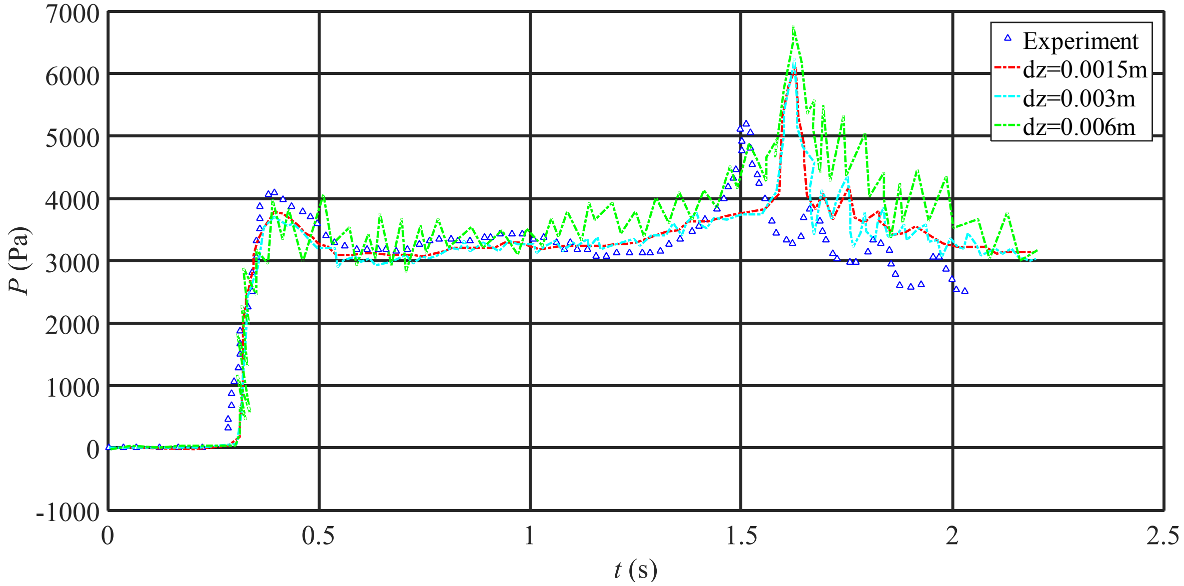

The air and the water are presented using the legend of velocity and pressure respectively. The numerical simulation is stable and the pressure and velocity field are smooth.

# 3. Numerical validation

## Dam breaking flow




The position of the pressure-measuring-point.



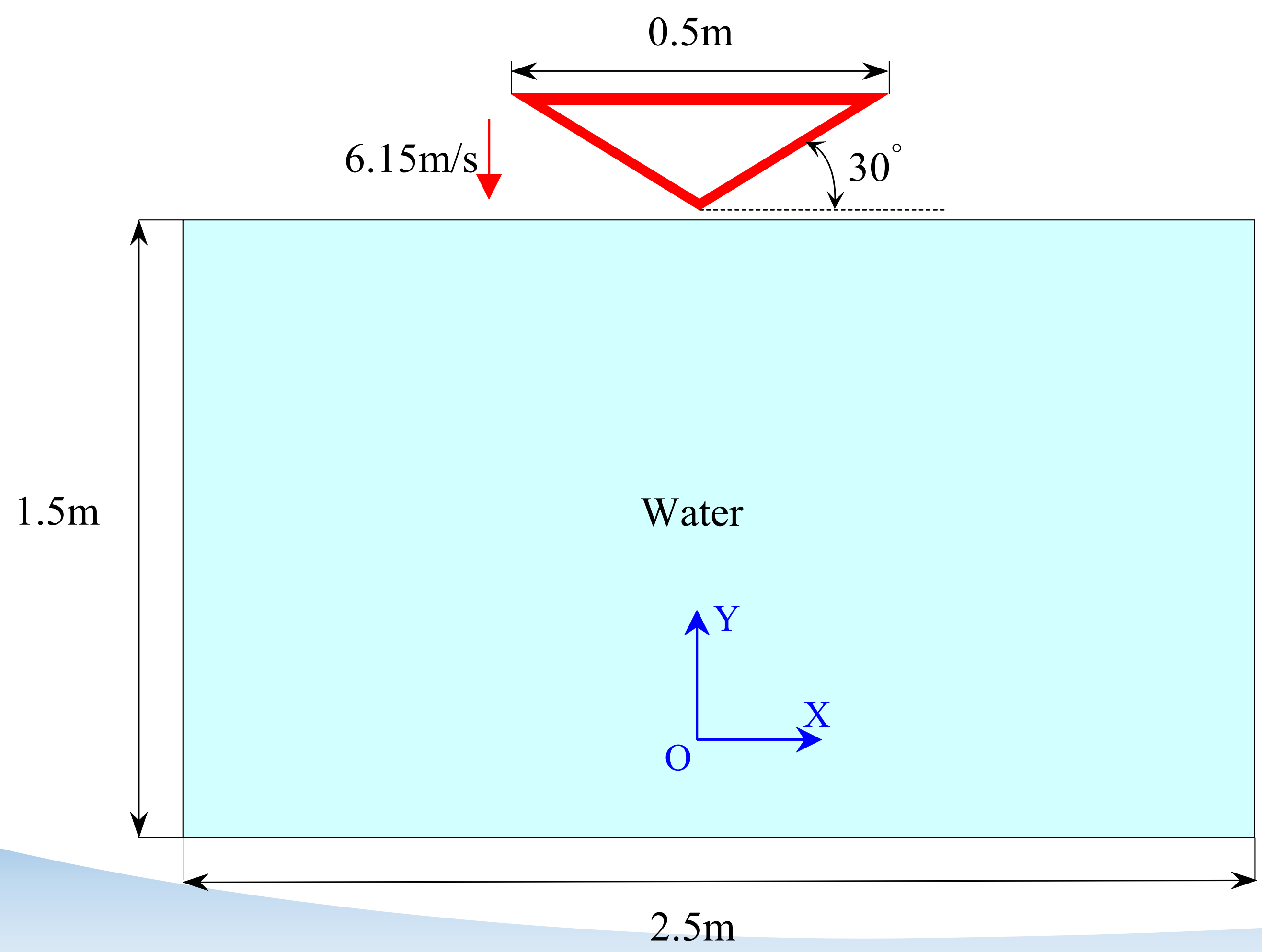

Time history of the pressure.

**The numerical results of pressure are in good agreements with the experimental results*, which proves the accuracy of the present multiphase SPH scheme.**

*Zhou, Z. Q., J. O. De Kat, and B. Buchner. "A nonlinear 3-D approach to simulate green water dynamics on deck." *Proceedings of the 7th International Conference on Numerical Ship Hydrodynamics*. Nantes, 1999.

# 4. Results and discussions

## 4.1 Water entry of the wedge.




Mass=241kg

$\rho_{air}=1.25kg/m^3$

$\rho_{water}=1000kg/m^3$

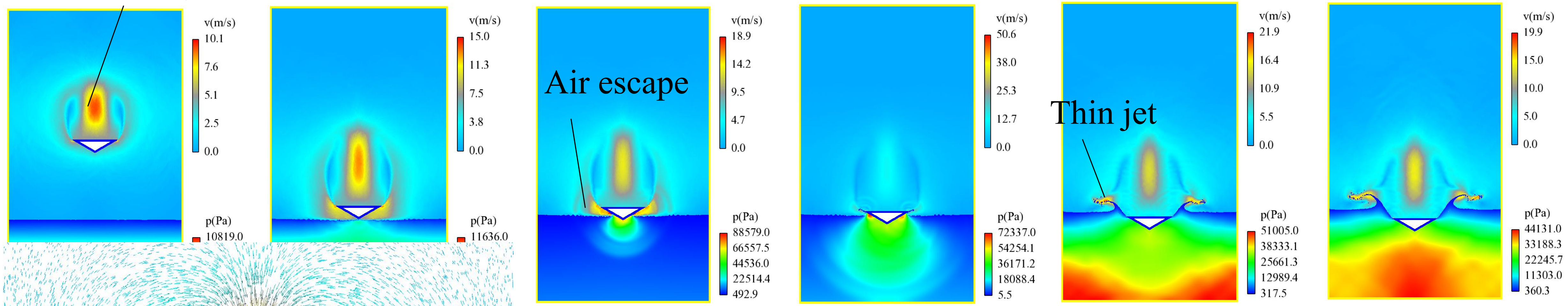
$C_{air}=340m/s$

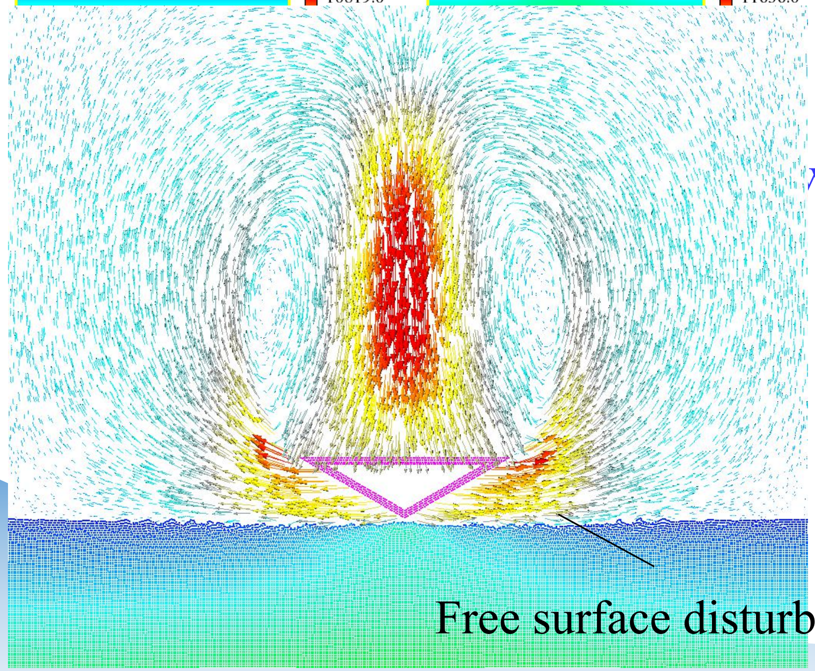
$C_{water}=61m/s$

Ma=0.1 (water)

# 4. Results and discussions

## 4.1 Water entry of the wedge.

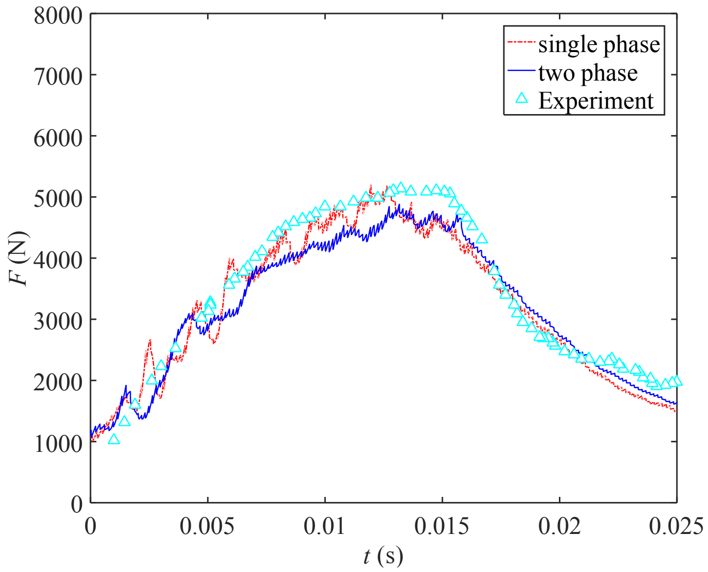


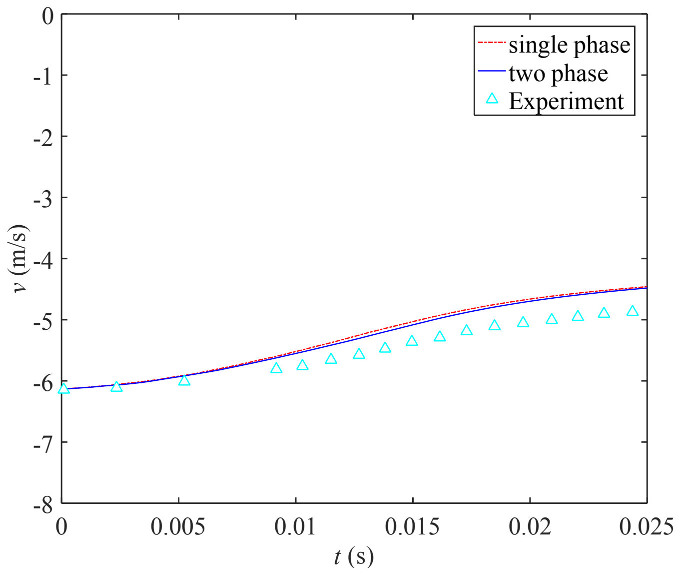

wedge water entry in a water tank. The air and the water are presented using the

# 4. Results and discussions

## 4.1 Water entry of the wedge.




Time history of the contact forces.



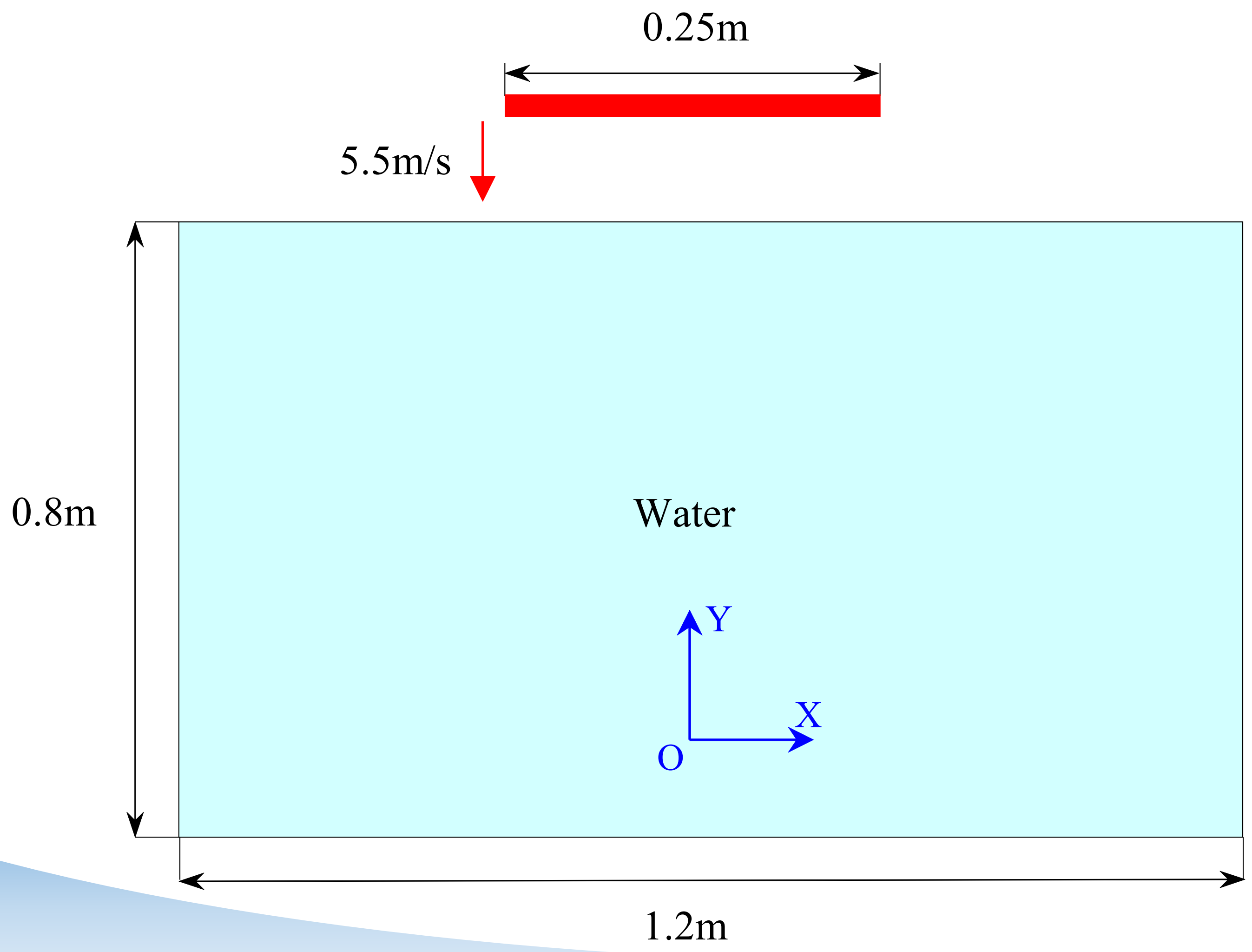

Time history of the vertical velocities.

**In general, the results from the multiphase SPH model agree well with the experimental data*.**

**R. Zhao, O. Faltinsen, J. Aarsnes, in Proceedings of the 21st symposium on naval hydrodynamics. (Trondheim, Norway, National Academy Press, Washington, DC, USA, 1996), pp. 408-423.*

# 4. Results and discussions

## 4.2 Water entry of the panel.




$\rho_{air}$=1.25kg/m$^3$

$\rho_{water}$=1000kg/m$^3$

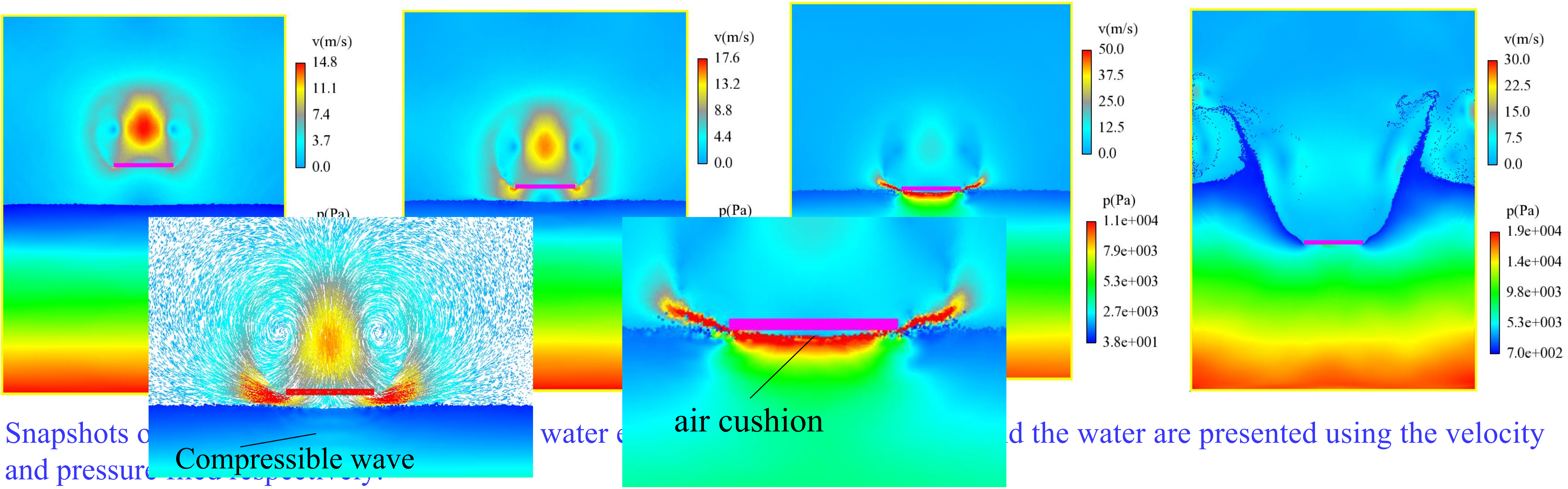
$C_{air}$=340m/s

$C_{water}$=(55~440)m/s

Ma= (0.0125~0.1) (water)

# 4. Results and discussions

## 4.2 Water entry of the panel.

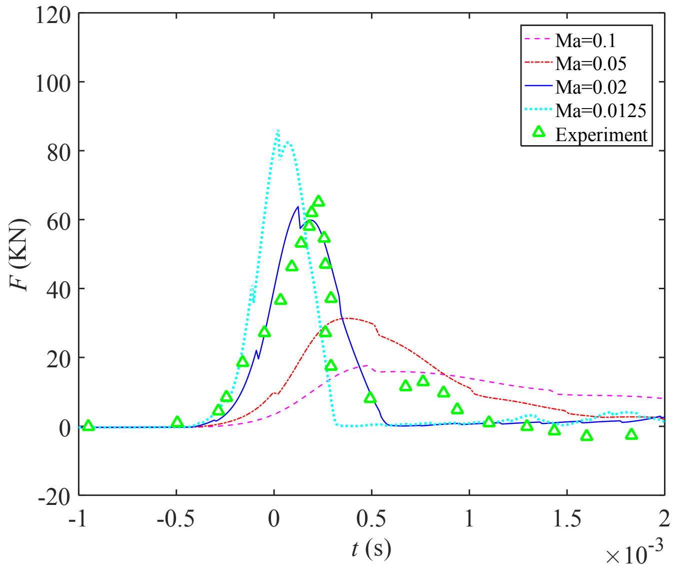



Snapshots o… water e…d the water are presented using the velocity and pressure filed respectively.

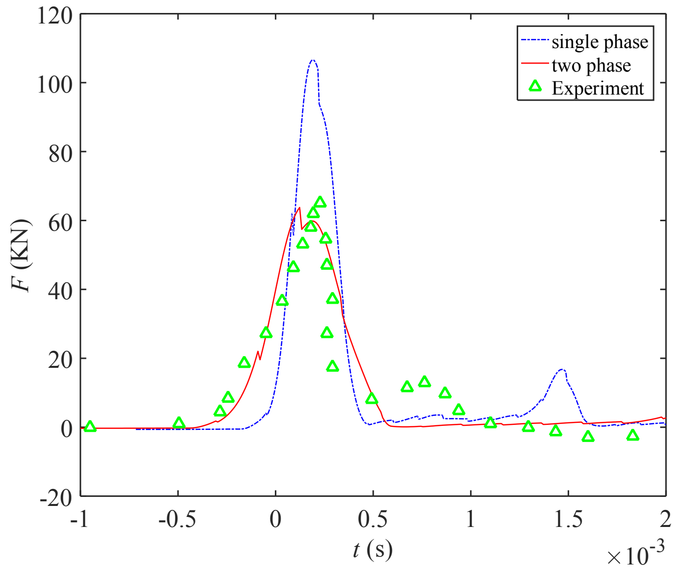
**The pressure filed and the velocity filed are stable during the water entry of the panel.**

# 4. Results and discussions

## 4.2 Water entry of the panel.




Time history of the contact forces during the impacting process with different Mach number.



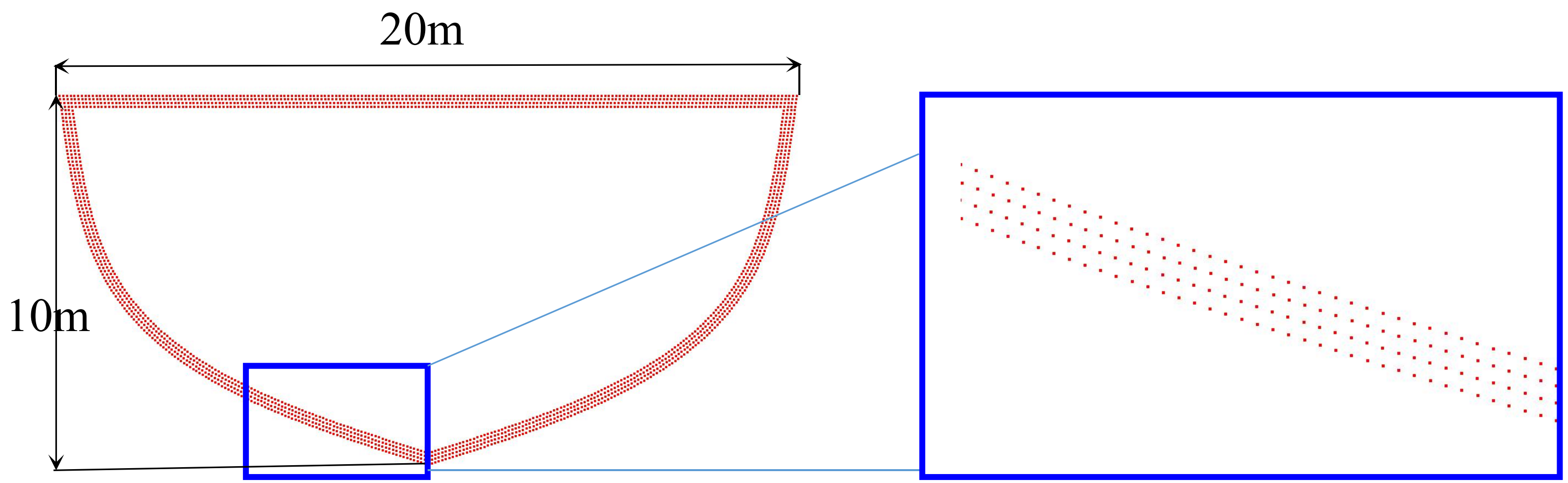

Time history of the contact forces during the impacting process with and without air.

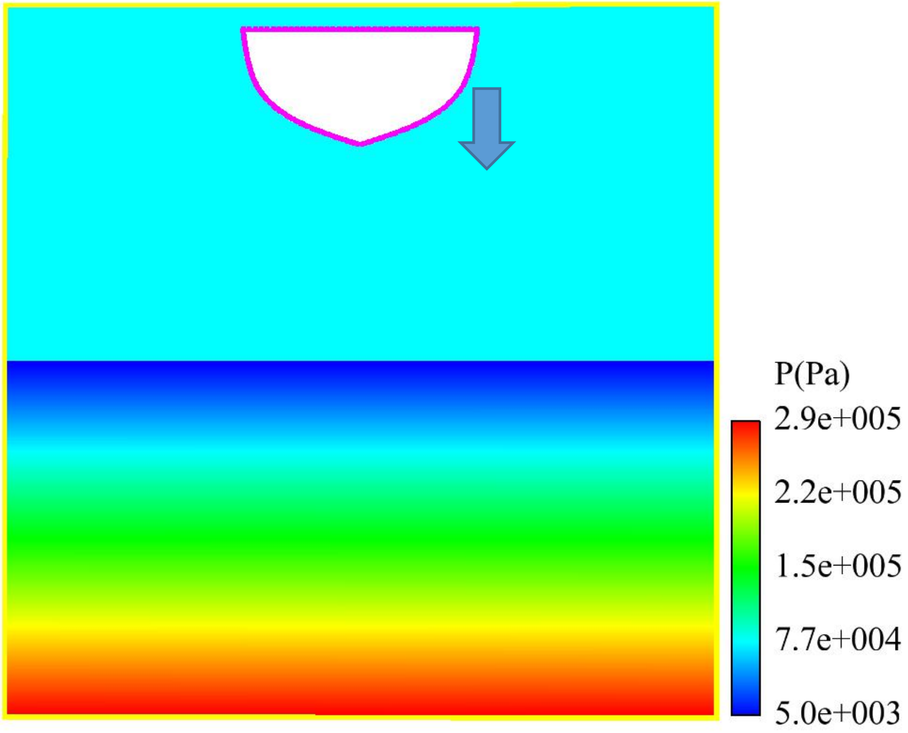
**It is found that the slamming load increases with the decrease of the Mach number rapidly. The numerical results tend to the experimental data* until the Mach number is adjusted to 0.02. And the slamming pressure when impact without air has a larger peak and a smaller time duration.**

*Z. Ma, D. Causon, L. Qian, C. Mingham, T. Mai, D. Greaves, A. Raby, Pure and aerated water entry of a flat plate. Physics of Fluids,28 (2016) 016104.*

# 4. Results and discussions

## 4.3 Water entry of the ship.



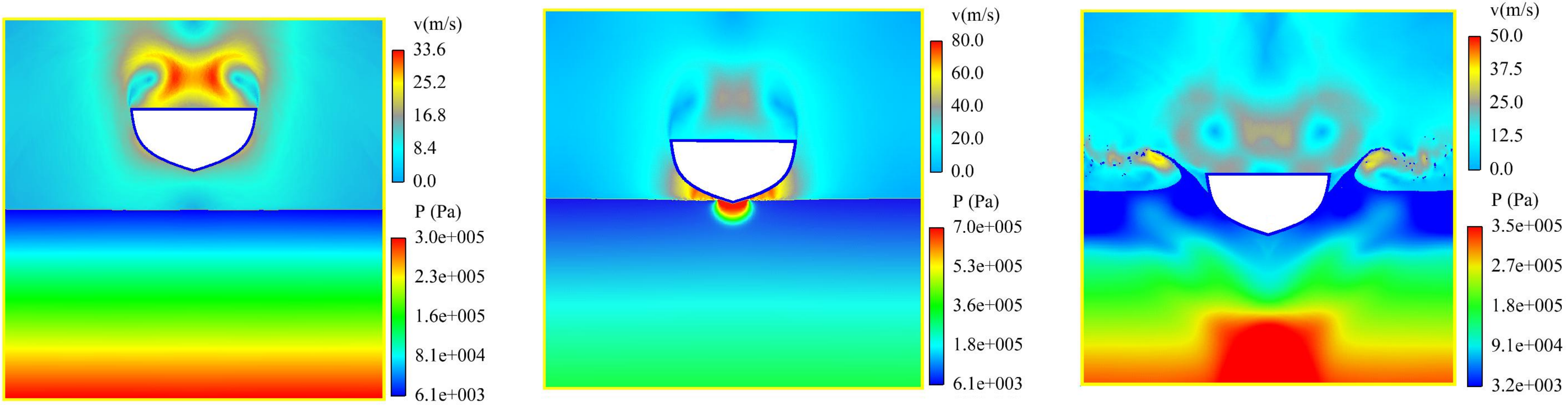




The initial setup of the model.

**The ship has an irregularly shape and it is discretized into four layers of particles. The ship entries water with a velocity of 6m/s.**

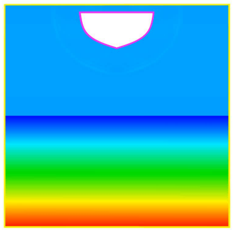
# 4. Results and discussions

## 4.3 Water entry of the ship.



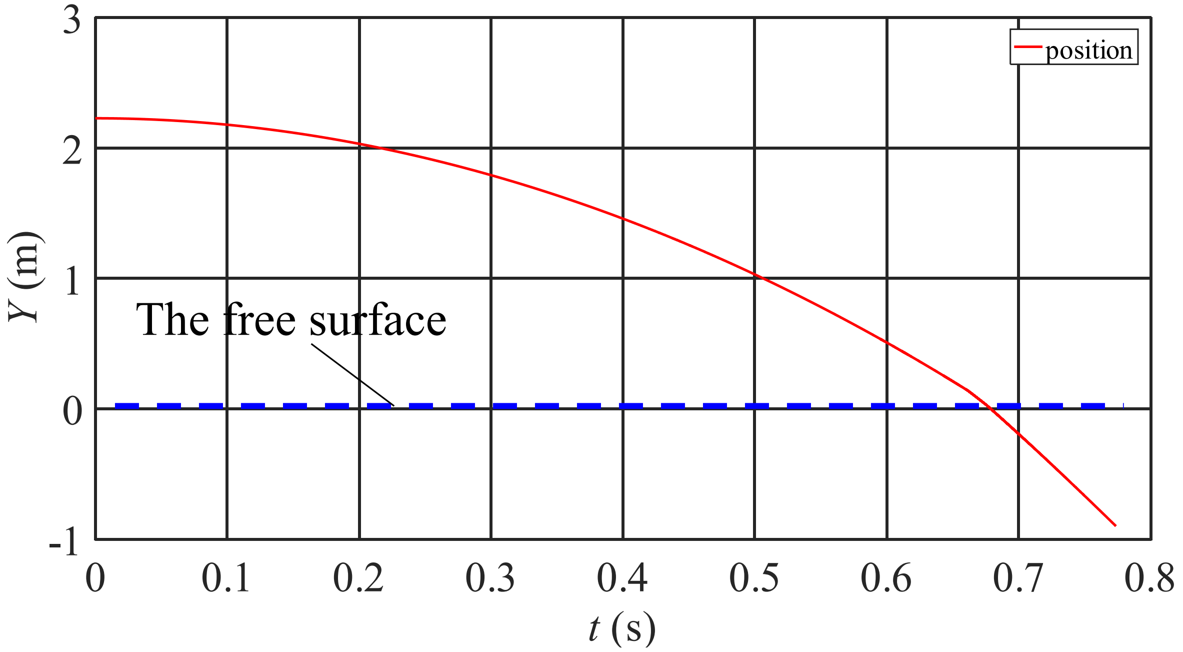

Snapshots of the evolution of the 2-D ship cross-section entry in a water tank. The air and the water are presented using the velocity and pressure filed respectively.

**An impact zone with high pressure is generated when the ship falls into the water domain.**

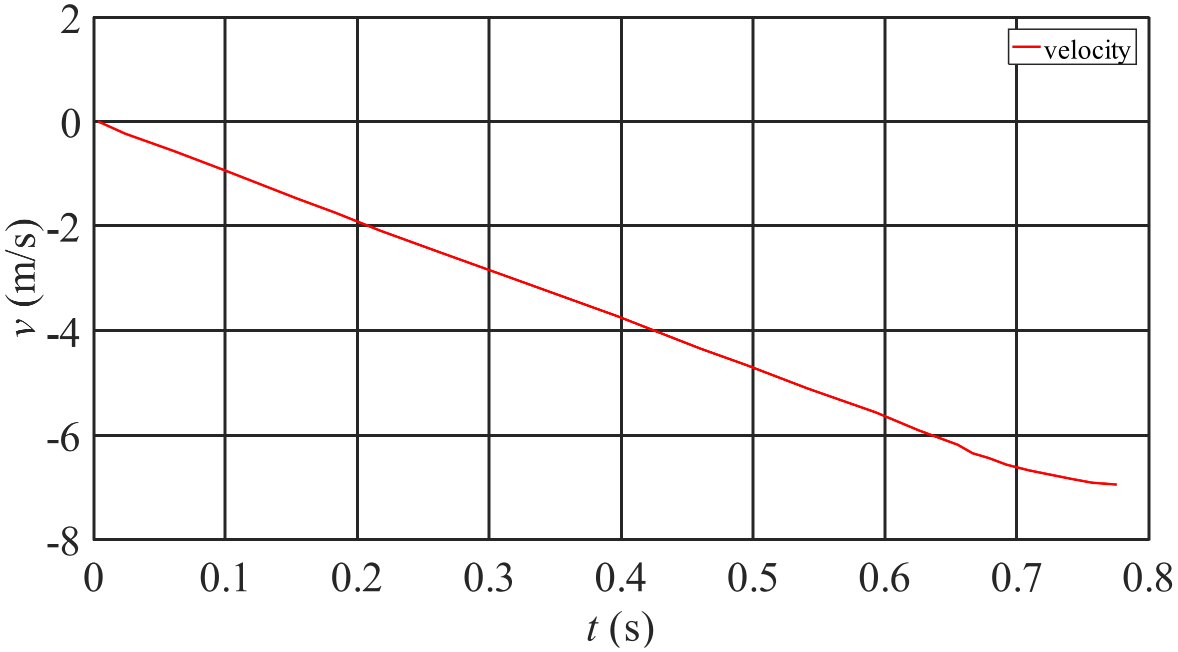


# 4. Results and discussions

## 4.3 Water entry of the ship.




The vertical position of the center of mass.




The vertical velocity of the ship .

# 5. Conclusions

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- ✓ The velocity and pressure fields of the air and the water are stable with a clear interface during the numerical simulation using the improved SPH model in the paper.
- ✓ The slamming forces for the water entry of the panel without air is bigger and has smaller pulse width.
- ✓ The value of the **Mach number** of the water can significantly influence the slamming forces for the water entry of the panel.

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Thank you!