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Numerical simulation of non-normal drop splashing using adaptive scheme

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Abstract

Understanding the dynamics of drop impact is the key to the study of diverse natural phenomena and to a wide range of technical applications. Drop impact dynamics is far from being understood both because of its complexity and the large number of parameters which influence it. The most important parameters are the Weber ($We = (\rho D V^2)/\sigma$), the Reynolds ($Re = (\rho D V)/\mu$) and the Ohnesorge ($Oh = \mu/(\rho \sigma D)^{1/2}$) numbers which are dimensionless groups. Three-dimensional numerical simulations of non-normal drop impact on thin liquid films are presented in this poster. The drop impinges the liquid film with different impingement angles, that is the angle between the trajectory of the drop and the free surface. The focus is on the description of the grid refinement technique used to follow the dynamics of the impact.

State of the art

Worthington is the first who investigated the phenomenon in exam in 1908 (Ref. [1]). He systematically investigated drop impacts on so-called deep pool –where the liquid depth is much larger than the drop size– and observed diverse dynamic behaviours after impact. The type of flow structure eventually observed depends on the drop velocity V, the impingement angle β, the dynamic viscosity μ, the density ρ, the size D of the drop (diameter) and the surface tension σ. Then Yarin and Weiss in 1995 (Ref. [2]) introduce a criterion to characterize normal drop impacts. From experimental data, they propose an approximate expression of the evolution of the radius of the crown as a function of time. Two-dimensional or axysimmetric numerical simulations of normal drop impact are performed in Refs. [3, 4]. Oblique drop impact is studied by Purvis et al., Hammond et al. and Quero et al. in Refs. [5, 6, 7]. Rieber and Frohn in 1999 (Ref. [8]) are the first who performed three-dimensional numerical computations. Nikolopoulos et al. in 2007 (Ref. [9]) reproduce the same impacts studied by Rieber and Frohn. Both papers use the Volume-Of-Fluid (VOF) method to study normal drop impacts. Nikolopoulos et al. also use an adaptive grid technique. Brambilla et al. in Refs. [10, 11] perform, respectively, normal and oblique drop impact in three dimensions.

Numerical results

The computational domain is shown in figure 1 and the boundary conditions are also reported. Only one half of the whole problem is simulated using the symmetry along the xy plane. In order to avoid a contraction of the liquid film towards the domain center, a tank is simulated. Therefore, there are three side walls and a lower wall located at $y = 0$.

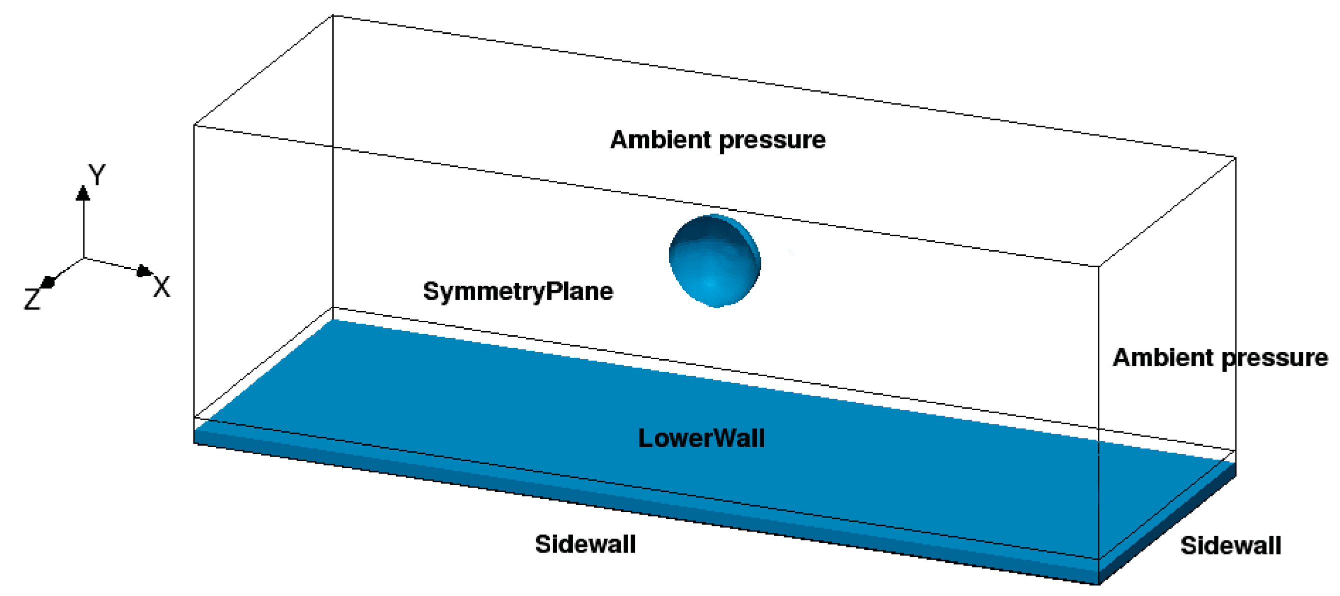


Figure 1: Computational domain

The numerical simulations cover a range of the impingement angle β from 10° to 90°. The Weber and the Ohnesorge number are equal, respectively, to 250 and to 0.0014. The dimensionless film thickness H=h_0/D, where h_0 is the film thickness, is 0.116. We consider three different refinement levels equal to 2, 3 and 4. The dimensionless time $\tau = t * V/D$ is equal to 10 in each case. Figures 2 and 3 show the computed gas-liquid interface for two different impingement angles equal to 20° and 80° with 4 refinement levels. The impact at 20° (figure 2) shows the evolution of a structure similar to the prow of a ship. From the impact at 80° (figure 3), it is clear that the front and the back rise quite to the same height normally to the free surface and this condition is reached at an impingement angle of 90°.

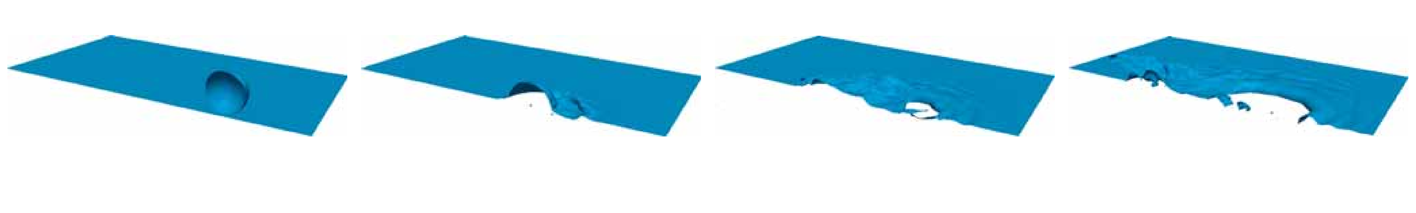


Figure 2: Computed gas-liquid interface for $\beta = 20^\circ$

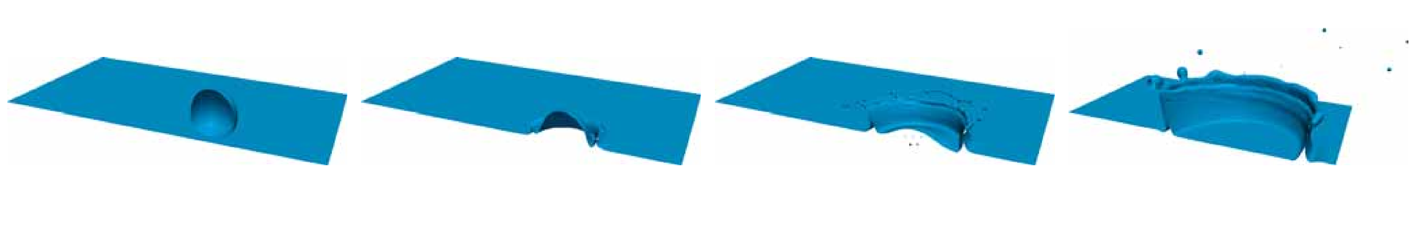
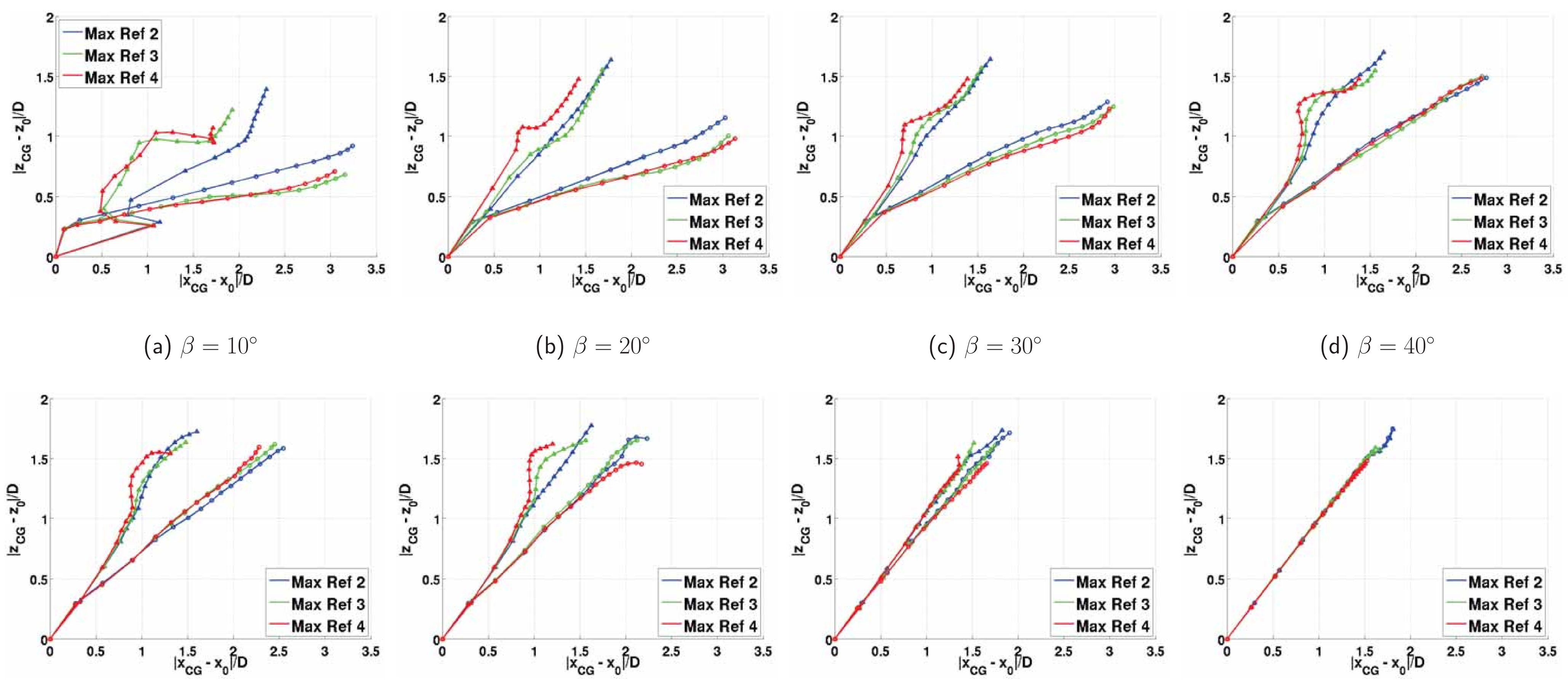


Figure 3: Computed gas-liquid interface for $\beta = 80^\circ$

In order to assess the grid convergence, we compute the coordinates of the center of gravity of both the front and the back at each time step. Therefore, three different discretizations are compared (see figure 4). From figure 4, it is clear that a refinement level of 2 gives trajectories far from those given by the other two discretizations for impingement angles less than 40°. Refinement level of 3 accurately describes the evolution of the drop impact almost as the refinement level of 4 and this means that we achieved a good grid convergence.



(a) $\beta = 10^\circ$ (b) $\beta = 20^\circ$ (c) $\beta = 30^\circ$ (d) $\beta = 40^\circ$

(e) $\beta = 50^\circ$ (f) $\beta = 60^\circ$ (g) $\beta = 80^\circ$ (h) $\beta = 90^\circ$

Figure 4: Trajectory of the centre of gravity: (◯) front and (△) back

The impact dynamics differs in each case. Figure 5 shows the evolutions of the impacts at impingement angles equal to $30^\circ, 40^\circ$ and 50°. The three series of figures point out that at impingement angles less than 40° there is the formation of a ship prow-like structure, as Okawa et al. show in Ref. [12]. At impingement angles greater than 40° a crown generates after the impact. The crown has an asymmetric shape which tends to become symmetric as the impingement angle increases.

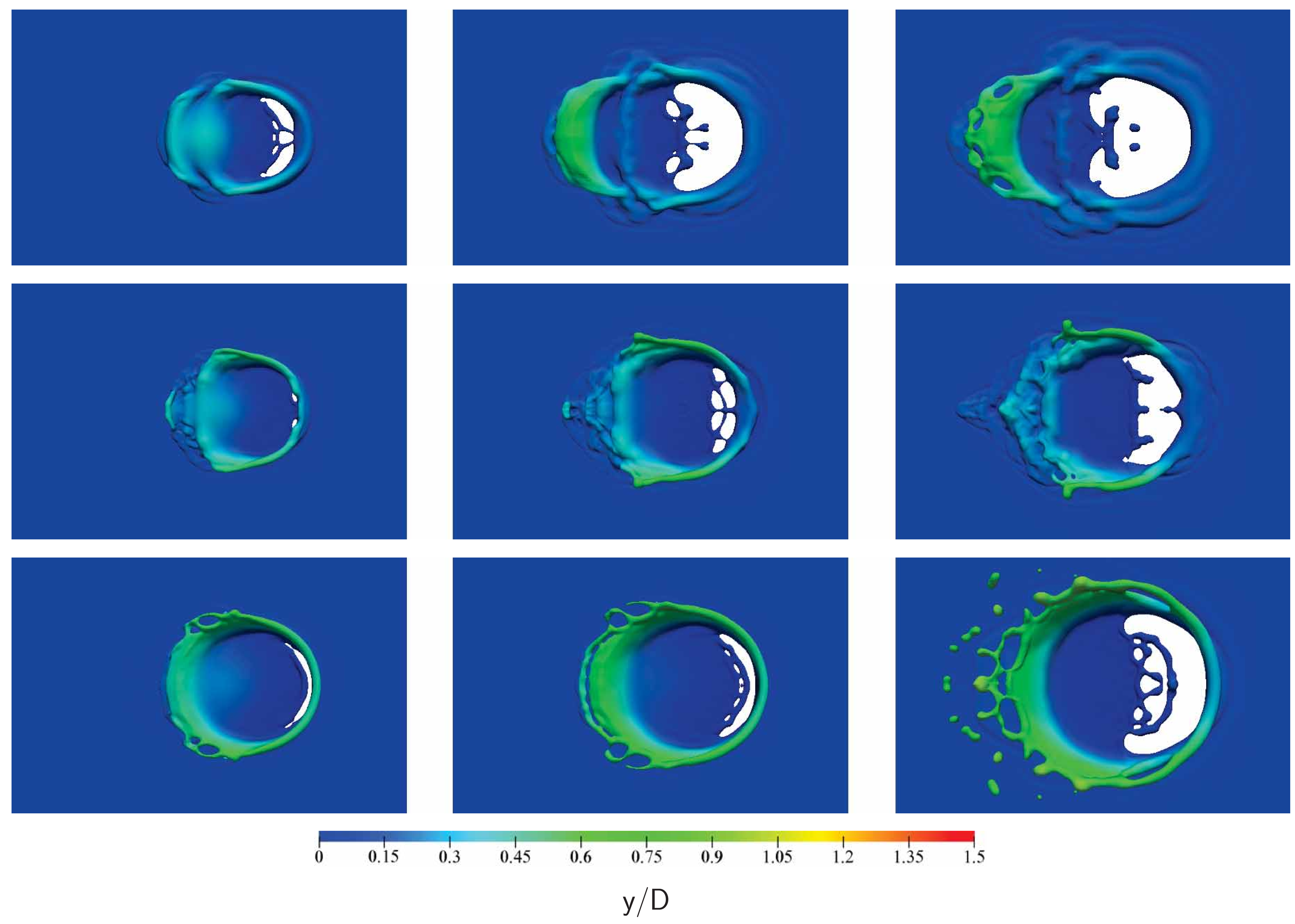


Figure 5: Region of transition: evolutions of the impacts at $\beta = 30^\circ; 40^\circ$ and 50° using one color scale for the height reached

Conclusions

A dynamic grid refinement method was used in three-dimensional numerical simulations of a single drop impact on a thin liquid layer. The adaptive technique allowed to refine some parts of the computational domain, that is the cells containing the gas-liquid interface. Therefore it was possible to save a great computational effort respect to a uniform grid. In order to assess the grid convergence, the numerical computations were performed with three different refinement levels. Present results suggest that for refinement levels greater than the major here considered, the results are independent from the grid.

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