Gas influence in drop impact on dry solid substrates

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Abstract. *A numerical study by the code GERRIS of drop impact onto a solid surface is presented. It is shown that under the incompressible assumption, drop impact can still perform different behaviors by changing the density or viscosity of surrounding gas, the splash can be suppressed for small gas density or viscosity and a no-vertical frontier exists between splash and non-splash. It is suggested that some aerodynamic instability can be crucial in the mechanism of splashing.*

Keywords: Drop; splash; impact; aerodynamic; lubrication; instability.

1 INTRODUCTION

Drop impact is wildly presented in nature as the soil erosion [1] and in a large number of industrial applications as metal sheet cooling, ink-jet printing and fuel atomization in combustion chambre. Drop impact has become in recent years one of the most exciting scientific subjects of multiphase flows [2, 3]. This complex triphasic dynamics can be simplified as a drop impact onto a solid surface. Until recently the surrounding gas influence has been neglected as a fact of the large density and viscous ratios between gas and liquid and it was believed that the gas could not play a crucial role in the impact dynamics. However, recent works have shown the crucial effect of surrounding gas in impact process [4]. There, drop impacts onto a solid substrate, as decreasing surrounding gas pressure from the atmospheric pressure to one fifth of an atmosphere, the splash disappeared and the drop was smoothly spreading on the solid substrate quickly for the lowest pressure(one fifth of an atmosphere). Since these emblematic results, different theories have been proposed as compressibility effects [5], rapid contact line motion, non-continuum gas effects[6] and aerodynamic instability [7]. However, the physical mechanism still remains unclear. In this article, we try to investigate the role of surrounding gas in drop impact onto a dry solid surface in an incompressible dynamics by numerical means.

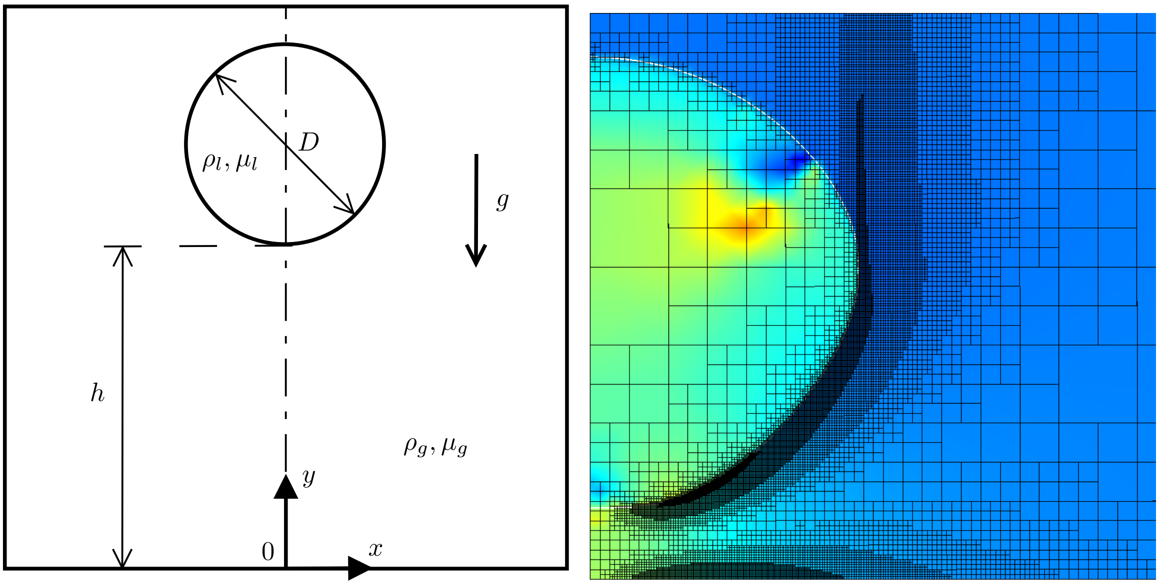
2 PROBLEM DESCRIPTION

2.1 Physical model

Our problem is shown in Figure 1(a). A liquid drop of diameter D, density ρ_l and viscosity μ_l falls from a certain height h under gravity g with a nul initial velocity U_0 and impacts onto a dry plane solid surface. The surrounding gas has a density ρ_g and a viscosity μ_g. The surface tension between gas and liquid is γ.
The dynamics of this diphasic system can be written within a unified two-dimensional Navier-Stokes equation considering gravity and surface tension for gas and liquid phase as :

$$\rho \frac{d\mathbf{u}}{dt} = -\nabla p + \mu \triangle \mathbf{u} + \rho \mathbf{g} + \gamma \kappa \delta \mathbf{n} \quad (1)$$

where the density and the viscosity fields take their proper values in each phase, $\mathbf{u} = (u, v)$ is the velocity, p is the



(a) Sketch of the drop impact onto a solid surface

(b) Snapshot of the adaptive mesh in the case of the drop impact onto a solid surface. The quadtree mesh is well refined in the crucial regions and the color scale represents the pressure

Figure 1: Sketch of the problem and snapshot of the adptive mesh arrangement

pressure, κ is the mean curvature of interface, δ is a two-dimensional delta function which insures that the surface tension is only at the interface and $\mathbf{n}$ is the normal vector to the interface.
Both fluids are considered incompressible in our dynamics, so that:

$$div(\mathbf{u}) = 0 \tag{2}$$

In the dynamics of the impact as the drop approaches to the solid surface, the gravity can be neglected. Such approximation is valid because the Froude number (or the aspect ratio):

$$Fr = \frac{U^2}{gD} = \frac{h}{D} \tag{3}$$

is high in the experiments that we consider. The whole dynamics is controlled by two dimensionless numbers, the Reynolds number Re which measures the relative importance of inertial forces to viscous forces:

$$Re = \frac{\rho_l U D}{\mu_l} \tag{4}$$

and the Weber number We which measures the relative importance of inertia compared to surface tension:

$$We = \frac{\rho_l U^2 D}{\gamma} \tag{5}$$

Two additional dimensionless numbers are introduced to describe the gas influence: the density ratio $r = \rho_g/\rho_l$ and the viscosity ratio $m = \mu_g/\mu_l$.
We investigate here a purely incompressible dependance of the impact dynamics on changing the gas properties by direct numerical simulation of the diphasic Navier-Stokes equation (1).

2.2 Numerical scheme

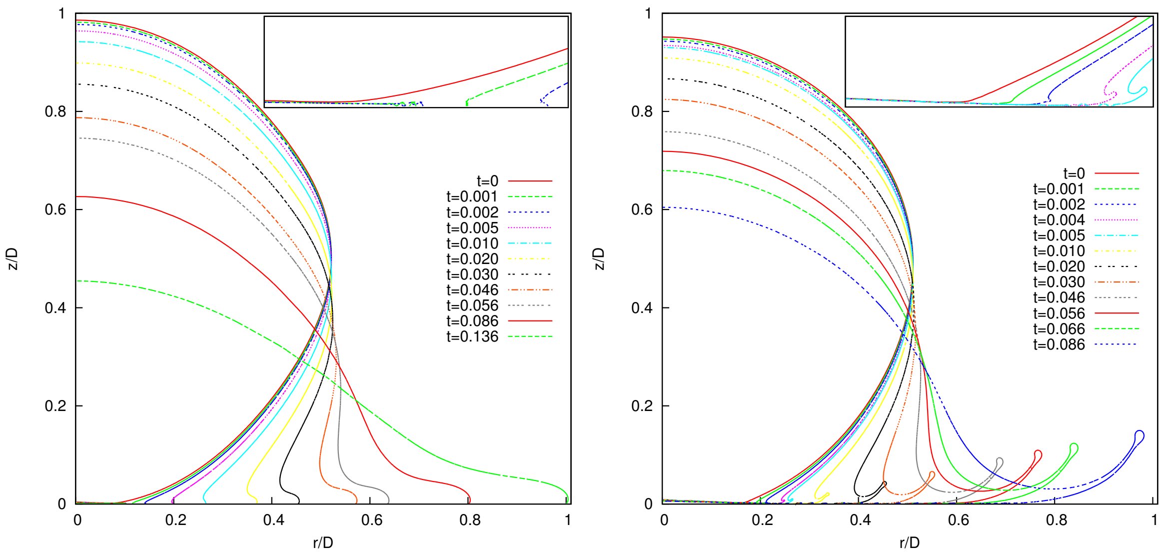
The incompressible diphasic Navier-Stokes equation (1) is solved in an axisymmetric and dimensionless form by a code called GERRIS(http://gfs.sf.net). GERRIS is a free, open-source software which is generally a solver of poisson-style equations based on the finite-volume discretisation, it uses an adaptive quad-tree/octree mesh generation technique [8, 9]and tracks the interface by a volume-of-fluid(VOF)/piecewise linear interface calculation method [10].

Thanks to the highly efficient adaptive techniques, this code has been successfully employed in many different fluid mechanics issues particularly in the interface dynamics [11, 12]. A snapshot of the quadtree mesh is shown in Figure 1(b) of the drop impact onto a solid surface. The mesh has been refined to catch both the interface region and the high vorticity zone.

The solid surface is considered half-wetting whoes corresponding contact angle θ is 90°.

3 RESULTS AND DISCUSSION

A series of numerical simulations has been done by changing the gas/liquid density or viscosity ratios, for constant Weber (We=1668) and Reynolds (Re=9350) numbers. Numerically only the gas viscosity and density vary among different simulations and liquid properties keep constant. In this paper, the free falling process is completely simulated from the very beginning. For different density or viscosity ratio, we observe the two expected behaviours. For a small viscosity ratio, no splash is observed (see Figure 2(a)) while a splash is formed when the gas viscosity increases (see Figure 2(b)).



(a) Non-splash (b) Splash

Figure 2: Snapshots of the drop profiles at different moments

By varying systematically the two ratios (of density and of viscosity) we get a phase diagram of the splash transition as shown in Figure 3 .

We observe that the viscosity ratio dominates the splash formation comparing to the density ratio, which agrees well with the dependence of the dynamics on the Stokes number which involves the gas dynamic viscosity. The non-splash/splash transition curve should be a vertical line according to the lubrication theory. However, in Figure 3, we observe that the transition deviates from the vertical line, particularly for small density ratios, which implies that another physical mechanism is important in the splashing formation.

4 CONCLUSIONS

As conclusion, in this article, we investigate gas influence in splash formation and try to understand the gas-pressure-depending phenonmena observed in experiments([4]). It is prooved by direct numerical simulations that the transition curve separating splash from non-splash regime depends on both the viscosity and the density ratios, which implies that compressibility is not strictly necessary to explain the experiments ([4]) although gas compressibility could be involved. It suggests that a mechanism involving the gas inertia can be present in the splash transition. Further theoretical, numerical and experimental studies are thus highly needed to get a clear vision of the splash formation upon drop impact.

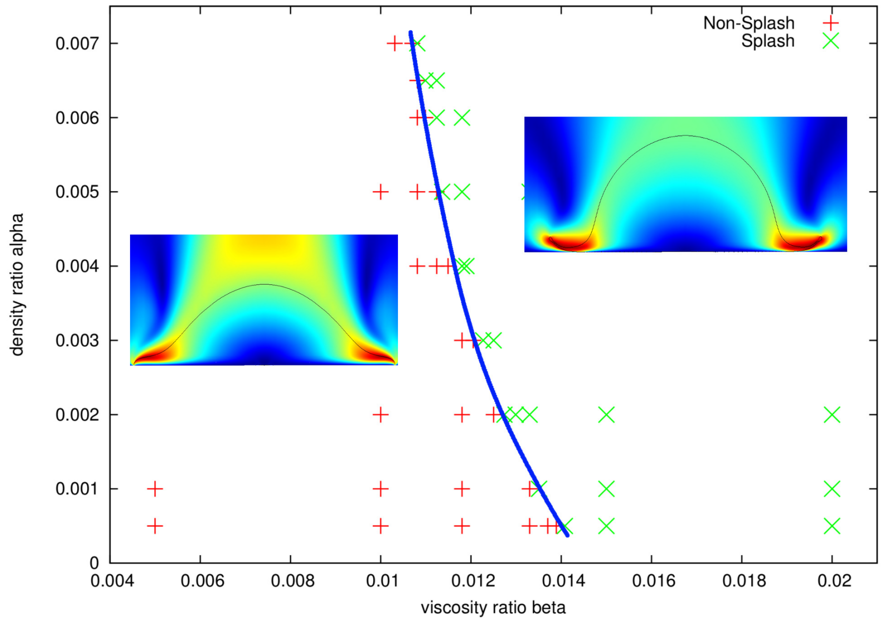


Figure 3: Phase diagram of the splashing process on varying density or viscosity ratios. Different from the incompressible lubrication theory, a dependence on the gas density is found.

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