SPREADING AND RETRACTION OF IMPACTING DROPS

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Summary We consider theoretically and numerically the axisymmetric dynamics of drop impacts on a hydrophobic solid surface. For reasonable Weber and Reynolds numbers the dynamics shows an initial spreading of the drop on the substrate followed by a retraction phase due to capillary forces. We perform a parametric study to investigate both capillary and viscosity influences on this dynamics. We particularly focus on the film thickness during the spreading. At early times of impact the ejected liquid lamella is determined for low Weber number by the capillary length. On the contrary for large Weber numbers we observe that the residual liquid film in the center of the impact at maximum spreading is controlled by viscous effects. The retraction dynamics is also captured and is clearly dependant on the liquid film thickness at the center. A simple Taylor-Cullick theory for receeding liquid film on solid substrate will be derived and compare to the numerical results for this hydrophobic case. More general situations with non trivial contact angle will be discussed.

INTRODUCTION

Drops impacting a wet or dry surface are a frequent and common process encountered in many geophysical, industrial and everyday-life situations. It is also well known to produce terrifi c pictures icons following the work of Worthington[1]. When the surface is perfectly dry and poorly hydrophilic, the drop fi rst spreads on the substrate until it reaches a maximum radius. Then surface tension drives the retraction of the expanded fi lm. Often a partial or complete rebond of the drop is observed creating a secondary droplet[2, 3]. The knowledge and the understanding of the maximum spreading radius and of the retraction dynamics for varying Weber and reynolds present important challenges both for fundamental mechanics and applications. Ink-jet printers need to control the maximum radius while the retraction dynamics is crucial for agricultural soil treatments[3]. Here we investigate numerically the dependance of these quantities with the Weber and Reynolds number for the specifi c case of hydrophobic surfaces.

NUMERICAL METHOD

We seek to solve the Navier-Stokes for axi-symetrical free surface flows:

$$\rho(\frac{\partial \mathbf{u}}{\partial t} + \mathbf{u} \cdot \nabla \mathbf{u}) = -\nabla p + \nabla \cdot (2\mu \mathbf{D}) + \sigma \kappa \delta_s \mathbf{n}$$

where ρ is the liquid density, $\mathbf{u}$ the velocity fi eld, and p the pressure. μ and σ are respectively the viscosity and the surface tension. κ is the axisymetric curvature, $\mathbf{n}$ the normal to the interface and $\mathbf{D}$ the rate of deformation tensor. The velocity fi eld is divergent free and the outer gas is neglected through free surface boundary conditions. The interface is tracked via a markers chains method developped by Popinet and Zaleski[4]. Two different boundary conditions will be taken at the wall. Firstly, the usual no-slip velocity condition on the wall is considered with $\theta = 180\circ$ constant contact angle. In that case, no typical moving contact line divergence is expected and would be if any suppressed by the numerical grid cut-off. On the other hand, following[2] we consider free-slip velocity conditions on the wall. The interface is captured through a marker-chain which is advected by the local velocity fi eld. Multigrid technics are used to solve the mass conservation.

IMPACT DYNAMICS

Typical drop shapes during the impact are shown on fi gure (1) for no-slip velocity boundary conditions and for high Weber and Reynolds number. The two fi rst pictures show the drop spreading into a flan thin pancakes. Between the third and fourth pictures, we observe the fi lm retraction driven by surface tension. On the other hand, the dynamics between pictures 2 and 3 occurs almost at constant spread radius. The liquid from the center of the drop is there continuously feeding the rim torus.

The maximum spreading radius is parametrically studied when Re and We vary. In particular we have isolated viscous and capillary effects through fi xed Weber or fi xed Reynolds numbers study. Although the viscous influence on the radius is hard to determine, it is relevant for low Reynolds number and the maximum radius shows only a weak dependance with the viscosity at high Reynolds number. However, a precise study of the residual fi lm thickness at the impact center shows a typical viscous layer dependance of this length. The capillary influence on the maximum spreading radius is stronger. For high Reynolds number, we compare our numerical results with two asymptotical theories predicting $We^{1/2}$ and $We^{1/4}$ dependance for high Weber numbers. We also discuss a phenomenological transition between small (order one) and high Weber numbers: at small Webers, we have shown[2] that capillary waves propagating along the surface determine the drop deformation. On the opposite case, for high Weber numbers these waves cannot propagate since they are slower than the impacting speed. The transition between these two behaviors will be discussed as a transsonic transition.

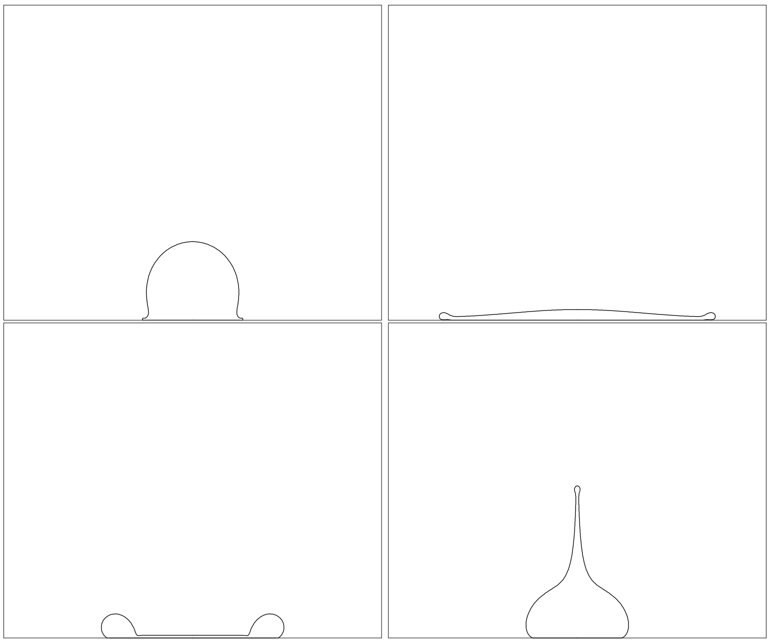

Figure 1. Drop shapes during the impact of a 3 mm water drop ($\mathrm{We} = 540$ and $\mathrm{Re} = 900$).

FILM RETRACTION

The dynamics of film retraction correspond for this hydrophobic situation to a particular dewetting dynamics. We are led to write a Taylor-Culick like theory of retracting film on a solid substrate. This theory accounts for viscous dissipation in the fluid by assuming that velocity gradients are determined by the film thickness. Comparison with 2D numerical simulation will be shown and an extension to non-hydrophobic will be discussed. Retraction speed dependance with capillary number will be calculated and compared with experimental situations.

CONCLUSIONS

The impact of droplets on dry solid surface is studied here following the inspiring hydrophobic case. Numerical simulations are compared with experimental results. We try to obtain consistant theories for the maximum radius expansion of the drop and for the retraction dynamics.

References

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