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Oblique Drop Impact on Deep and Shallow Liquid

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Abstract. Numerical simulations using CLSVOF (coupled level set and volume of fluid) method are performed to investigate the coalescence and splashing regimes when a spherical water drop hits on the water surface with an impingement angle. Impingement angle is the angle between the velocity vector of primary drop and the normal vector to water surface. The effect of impingement angle, impact velocity and the height of target liquid are carried out. The impingement angle is varied from 0^o to 90^o showing the gradual change in phenomena. The formation of ship pro like shape, liquid sheet, secondary drops and crater are seen. Crater height, crater displacement, crown height and crown angle are calculated and the change in the parameters with change in impingement angle is noted.

AMS subject classifications: 65M06, 76D45, 76T10

Key words: Coupled level set and volume of fluid method, drop impact, impingement angle, Weber number.

1 Introduction

The various phenomena during drop impact on a liquid surface have both natural and industrial significance. Liquid spray cooling, ink-jet printing, fuel injection in engines, shock atomization, underwater noise of rain is some such examples. Worthington [1] is considered the first to investigate it systematically. Normal drop impact on deep liquid surface has been extensively studied by Rein [2] and Liow [3]. Different regimes from coalescence to splashing are described. The transition between these regimes is defined based on the relation between Weber number $We=\rho U^2 D/\sigma$ and the Froude number

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$Fr = U^2/gD$ where ρ is the drop density, U its velocity, D its diameter, σ the surface tension and g is the acceleration due to gravity. At very low impact velocities, the impinging drop has been observed to coalesce with the bulk liquid but may also bounce or float. As the impact velocity increases, the formation of central jet with splashing droplets is observed. The transition between coalescence and splashing proceeds through a regime where a thick central jet is formed followed by a regime where bubble entrapment coupled with a thin high speed jet is observed. In case of shallow liquids or thin films, Weiss and Yarin [4] showed analytically and numerically different phenomena- neck distortion, jetting, bubble entrainment and the crown formation.

Compared to normal drop impact, oblique drop impact on liquid is not much studied. Most notable are the works of Leneweit et al. [5] and Okawa et al. [6]. Leneweit et al. [5] studied the oblique impact of a single drop on deep fluids for Weber number ranging from $15 \le We \le 249$ and impingement angle $5.4^o \le \theta \le 64.4^o$. They mainly described the different regimes within this range and found empirical relation. Okawa et al. [6] on the other hand have mainly investigated on the total mass of secondary drop formed during oblique collision. There range of Weber number was $7.2 \le We \le 818$ and impingement angle was $11^o \le \theta \le 75^o$.

The CLSVOF (coupled level set and volume of fluid) method is used to validate various experimental results. The volume of fluid (VOF) method of Hirt and Nichols [7] forms the building block of computations involving two fluids separated by a sharp interface. The VOF method satisfies compliance with mass conservation extremely well. The disadvantage of VOF method is that sometimes it is difficult to capture the geometric properties of the complicated interface. Another efficient interface-capturing method, known as the level-set (LS) method was first introduced by Osher and Sethian [8]. This method captures the interface very accurately but in some cases it may violate the mass conservation. To achieve mass conservation as well as capture the interface accurately the level set methodology is coupled with the VOF method, known as the CLSVOF method. In the CLSVOF method [9], the level set function is used only to compute the geometric properties at the interface while the void fraction is calculated using the VOF approach. Chakraborty et al. [10] have extended this method to simulate bubble formation from submerged orifice in quiescent liquid.

In the work of Leneweit et al. [5] and Okawa et al. [6], the nondimensional height of bulk liquid was $H^*(=h/D) > 1$. In the present paper the two heights $H^* = 2.5$ (deep liquid) and $H^* = 0.5$ (shallow liquid) are taken with Weber number values $We = 49$ and 217 and impingement angle $0^o \le \theta \le 90^o$. Thus the gradual change in the phenomena due to increase in impingement angle is studied here.

2 Computational domain and numerical method

Complete numerical simulation of the processes is performed for two-dimensional incompressible flow as shown in Fig. 1. The rectangular domain used for the simulation