NUMERICAL SIMULATION OF DROP IMPACT ON A LIQUID-LIQUID INTERFACE WITH A MULTIPLE MARKER FRONT-CAPTURING METHOD

Emil Coyajee, Bendiks Jan Boersma
J.M. Burgerscentrum for Fluid Mechanics, Delft University of Technology,
Laboratory for Aero & Hydrodynamics, Leeghwaterstraat 21,
NL-2628 CA Delft, The Netherlands
e.r.a.coyajee@tudelft.nl

Abstract

The gravity-driven motion of a droplet impacting on a liquid-liquid interface is studied. The full Navier-Stokes equations are solved on a fixed, uniform grid using a finite-difference/front-capturing method. For the representation of fluid-fluid interfaces, a coupled Level-Set/Volume-of-Fluid method [22] is used, in which we introduce the novel approach of describing separate interfaces with different marker functions. As a consequence, we prevent numerical coalescence of the droplet and the liquid-liquid interface without excessive (local) grid refinement. To validate our method, numerical simulations of the drop impact event are compared with experiments [16]. The investigation shows that while the multiple marker approach successfully prevents numerical coalescence of interfaces and adequately captures the effect of surface tension, insufficient resolution may be available to represent fluid motion in the thin film between colliding droplets. Nevertheless, the results of the drop impact study imply that the multiple marker method can be readily used when the viscosity ratio of the fluid phases is of order unity.

1 Introduction

For the direct numerical solution of multiple droplets in a viscous fluid, some of the most commonly used methods either belong to the class of front-capturing or front-tracking methods. Using either one of these methods to simulate droplet interaction, one is confronted with the wide range of length scales involved.

When two droplets collide, a thin film of the surrounding liquid persists between the droplets, requiring a certain drainage time before coalescence may take place. Depending on the size of the droplets and the material properties of the fluids, the thickness of the thin film can be much smaller than the radius of the droplet (figure 1). In a numerical simulation, representation of such thin films requires extensive grid refinement, which is exceptionally expensive when the fluid motion is computed on a fixed, uniform grid. Although local adaptivity of the mesh refinement can be considered in anticipation of the random motion of droplets in a dispersion, its implementation substantially contributes to the complexity of the algorithm. Alternatively, if the thin film is not resolved in a numerical simulation, front-tracking and front-capturing methods may give qualitatively very different results because of different interface representations.

In front-capturing methods, the moving, deformable interface is defined implicitly by a marker function on the fixed grid. As a result, standard front-capturing methods, such as Level-Set (LS)

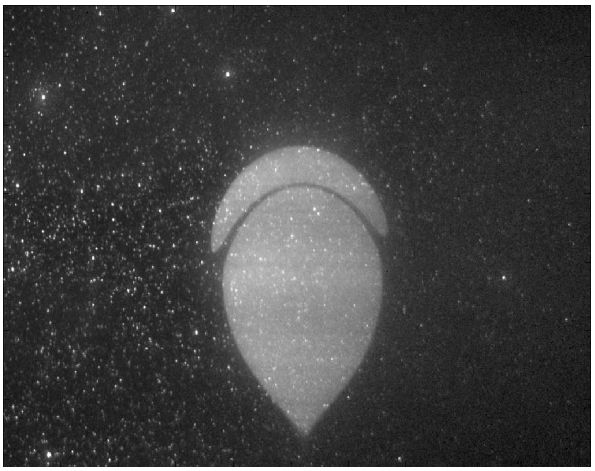

Figure 1: Collision of two oil drops rising in a glucose-water mixture at low Reynolds and low Weber number conditions [4].

[23, 2], Volume-Of-Fluid (VOF) [18, 13, 10] or combined LS/VOF methods [22, 25] are not capable of representing multiple interfaces in a single computational cell. When the interfaces of different droplets collide, they merge automatically, resulting in so-called numerical coalescence of the droplets.

In case of front-tracking, the interface is defined explicitly by means of a set of logically connected particles [24]. Consequently, multiple interfaces can easily be represented in a single cell and droplet collision without coalescence is naturally simulated. To merge interfaces, special effort needs to be made. In the region of merger, some interface particles are deleted while the remaining ones need to be reconnected.

In conclusion, although front-tracking enables simulation of interfaces both with and without coalescence, standard front-capturing methods are limited to automatic merging of interfaces upon collision. Therefore, front-capturing methods have been combined with particle tracking in recent years. Combined particle/VOF [1, 12] and particle/LS [5] methods have been proposed to capture interfaces at sub-cell resolution, however at the cost of introducing additional complexity compared to the original VOF or LS methods.

In this work, we propose a different strategy to simulate non-coalescing interfaces with a front-capturing method. The concept is to use separate marker functions for the interfaces of different volumes of the same fluid. It will be shown that only small adjustments to the traditional, single marker front-capturing method are required, adding little complexity to the algorithm. To validate the multiple marker front-capturing method, it is applied to the problem of the gravity driven impact of a droplet on a liquid-liquid interface. Essentially, this problem is equivalent to the problem of the collision of two droplets, one of finite and one of infinite radius. Our results are compared with the detailed experimental study of drop impact on a liquid-liquid interface by [16].

In the next section, we first present the governing equations for interfacial two-phase flow. Subsequently, our traditional front-capturing method is discussed, which is based on a definition of different bodies of the same fluid with a single marker function. Then, in section 4 the concept and implementation of the multiple marker approach is introduced. Subsequently in section 5 the drop impact study is presented. Here, following a motivation of the numerical set-up, a detailed comparison between numerical results and experimental observations is displayed. In section 6, the chapter concludes with