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# Impact Dynamics of Binary Off-Center Unequal-Sized Droplets Colliding on a Superhydrophobic Surface

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**Abstract.** We present a numerical study that investigates the collision between a falling droplet and a sessile droplet on a superhydrophobic surface with various impact velocities, size ratios, and eccentric angles. After impact, the two droplets may merge into a bigger droplet. We use the OpenFOAM volume of the fluid method to monitor the droplet geometry, analyze the dynamic characteristics of the impact, determine the contact time of the merged droplet on the surface, and locate the contact line of the merged droplet. When a large droplet impacts a small droplet, increasing the eccentric angle decreases both the maximum spreading distance and the contact time for all impact velocities. Additionally, it reduces the number of broken small droplets that splash following fragmentation at high impact velocity. Droplets of equal size produce impacts that are nearly the same as those of a large droplet impacting a small droplet. The only difference occurs at the moment of droplet fragmentation. When a small droplet impacts a large droplet, increasing the eccentric angle by less than 10° shortens the maximum spreading distance while only slightly increasing the contact time. In addition, droplet fragmentation is significantly reduced. The results provide insight into potential applications of droplet-solid interactions, which are valuable for engineering applications such as anti-icing and self-cleaning.

**AMS subject classifications**: 76T10, 76M12, 76D05

**Key words**: Droplet impact, droplet size, eccentric angle, superhydrophobic surface.

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# 1 Introduction

Droplet impact dynamics have recently attracted significant attention due to their potential implications in various domains, including daily life and industrial applications. This phenomenon, which is evident in nature (e.g., the formation and descent of raindrops), has practical use in industries such as spray cooling [1], spray coating [2], spraying pesticides [3], preventing ice formation on aircraft wings [4], and designing self-cleaning hydrophobic substrates [5].

Numerous studies have been conducted, and considerable progress has been made in understanding the impact of a single droplet on a solid surface. Collisions between droplets are influenced by several parameters, including droplet impact velocity, droplet size, liquid properties, and substrate wettability [6–8]. Li et al. [9] observed experimentally that a liquid film on top of a pillar produces a wet surface instead of a dry surface as the water droplet recedes from the textured surface, which affects the falling speed or rebound height of droplets. Zhang et al. [10] used the lattice Boltzmann method to investigate the oblique impact of individual rain droplets on a superhydrophobic surface with randomly distributed rough structures. Due to reduced energy consumption caused by the pinning effect, an oblique impact was found to reduce the contact time during droplet rebound.

Many studies have considered the impact of multiple liquid droplets on solid surfaces. Wang et al. [11] used the lattice Boltzmann model to investigate droplet pairs separated by different distances and that collide with one droplet on a superhydrophobic surface. The results revealed three rebound patterns: complete-coalescence rebound, partial-coalescence rebound, and no-coalescence rebound. Abouelsoud and Bai [12] studied the collision of a falling drop with a sessile drop on different solid surfaces at low Weber number $(We)$. They observed that complete rebounding often occurs upon impact on hydrophilic surfaces, with a restitution coefficient $\varepsilon \sim We^{-1/2}$. Cheng et al. [13] simulated the head-on impact of unequally sized droplets on a superhydrophobic surface and concluded (i) that the surface energy released by the two droplets coalescing mainly contributes to the energy of droplet jumping, (ii) that the contact time between the droplets and the superhydrophobic substrate is proportional to $We^{0.5}$, and (iii) that the maximum expansion diameter of the merged droplet is proportional to $We^{0.2}$. Jaiswal and Khandekar [14] investigated drop-on-drop impact on a superhydrophobic surface. Given a low Weber number of the impact droplet, three merging processes are possible: gentle merging, late merging, and droplet rebound without merging. However, given a high Weber number of the impact droplet, the results tend to homogenize, and the droplets merge, spread, recede, and rebound from the substrate.

Droplets do not always collide head-on in engineering applications such as anti-icing and self-cleaning. Three modes of collision are possible when a stationary droplet is impacted by another droplet [15]: (a) the two droplets collide head-on, (b) the impacting droplet vertically collides on one side of the stationary droplet, and (c) the impacting droplet collides on the other side of the stationary droplet with the direction of the im-