FLUID DYNAMICS

Shaping drops

A surface made from an array of widely spaced tapered posts enables water drops that hit it to bounce off with a pancake-like shape. This finding provides new strategies for reducing the contact time of drops impacting on surfaces.

Doris Vollmer and Hans-Jürgen Butt

When a drop hits a surface, it may bounce back, it may stick or it may splash into many small droplets. High-speed microscopy can reveal the dynamics of the impact in detail — the resulting images are an intriguing and visually appealing sight. Drop impact is a fascinating field of scientific research with early studies dating back to more than a century ago[1]. Harold Edgerton — a high-speed photography pioneer — had already recorded drop impact with millisecond resolution using a homebuilt stroboscope 75 years ago[2]. Today, there is still a need to understand and manipulate drop impact for applications like printing, spray coating, heat transfer control or the prevention of icing.

Whether the drop bounces, sticks or splashes depends first on the properties of the drop itself: its size and velocity, and the density and surface tension of the liquid[3]. Second, the air surrounding the drop influences the impact[4,5]: although the viscosity of air at normal pressure is much lower than that of a liquid, it can still stimulate bouncing and splashing. Third, the chemical composition of the surface and its structure on the micro- and nanoscale decides the fate of an impacting drop.

As they report in *Nature Physics*, Yahua Liu and colleagues[6] have now made a significant step towards understanding the influence of the details of surface topography on drop impact. Using a cleverly designed superhydrophobic surface, they were able to make originally spherically shaped water drops bounce from the surface with the distinct shape of a flat disc. This surprising scenario, termed 'pancake bouncing' by the authors, can be rationalized by a simple theoretical model based on inertia and capillarity.

Until now it was believed that drop impact could always be separated into two phases: spreading and retracting[7]. In the spreading phase, an impacting drop (Fig. 1a) experiences an effective lateral acceleration that flattens it (Fig. 1b). The kinetic energy is converted to interfacial energy. In the retracting phase, the drop balls-up again, minimizing its interfacial energy. It recoils, unless the impact velocity is so high that the rim breaks and the drop splashes.

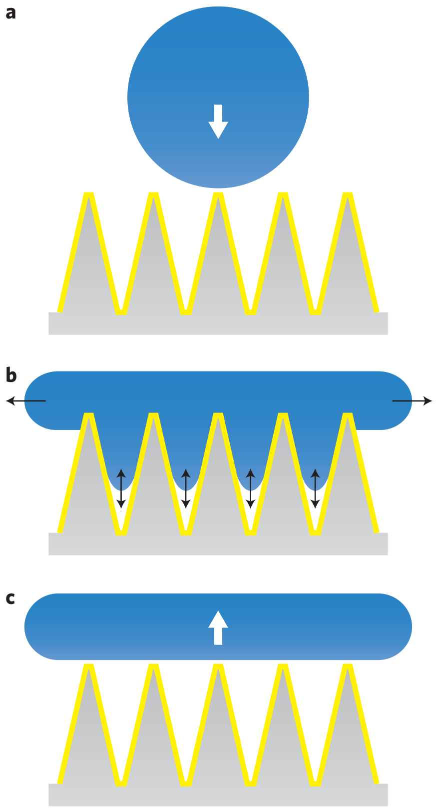

Figure 1 | Drop impact dynamics usually displays two phases: spreading and retraction. Liu *et al.*[6] now show that a drop can lift-off from a surface before retraction sets in. This greatly reduces the contact time of the drop with the substrate. **a**, A spherical drop just before hitting the structured surface. **b**, Spreading and retraction dynamics can be modelled as a Hooke spring in both the horizontal and vertical directions. To decrease friction with the walls, the surface of the posts is coated with a superhydrophobic layer (yellow). **c**, Lift-off.

On a superhydrophobic surface, an impacting drop slides over air cushions that are trapped beneath it. The transformation of the drop's kinetic energy into interfacial energy is almost complete. During retraction, energy is dissipated by the drop's adhesion to the top areas of the rough hydrophobic surface, which is, for example, made of regularly shaped posts. Research has focused on small posts because adhesion decreases with the diameter of the posts. Furthermore, penetration of the water into the superhydrophobic structure causes wetting and must be prevented. Drops deposited on a surface with small inter-post spacing can tolerate a high pressure before the air cushion collapses as the opposing Laplace pressure increases with the inverse of the spacing. In addition to the spacing, the height of the posts is important. High posts enhance water repellence, whereas short and wide posts offer good mechanical stability[8].

Liu *et al.*[6] fabricated posts with a height of almost 1 mm and a width and inter-post spacing of more than 0.1 mm — characteristic dimensions that are one order of magnitude larger than those typically used for superhydrophobic post arrays. Moreover, the authors coated the surface of the posts with a nanoscopic superhydrophobic layer (marked yellow in Fig. 1), resulting in a two-tier structure. This design has several advantages. One is high mechanical stability due to the large width of the posts. A second advantage is more relevant for drop impact itself: usually, when a drop hits a surface, its momentum is transformed into horizontal flow, inducing lateral spreading over the surface. For the widely spaced, large posts used by Liu *et al.*, the vertical flow component of the impacting liquid leads to penetration of the liquid into the space between posts (without touching the base) over a region approximately the size of the cross section of the initial drop (Fig. 1b). Penetration is followed by upward capillary emptying — the stored capillary energy is transformed back into kinetic energy — enabling lift-off (Fig. 1c). In the case of tapered posts, with a radius that increases with depth, the acceleration of the penetrating liquid increases with penetration depth. This permits modelling of the capillary force as a harmonic spring. The timescales of lateral spreading and vertical penetration balance out — pancake bouncing becomes independent of impact velocity. A prerequisite, however, is that the posts are superhydrophobic. This greatly reduces viscous friction during capillary emptying and ensures that enough capillary energy is stored for the subsequent lift-off. As lift-off starts before recoiling begins, pancake bouncing enables a reduction of the contact time by a factor of over four.

Pancake bouncing provides an intriguing example of how the shape of a rebounding drop can be engineered by means of well-designed surface texturing. The (at first sight) counterintuitive topography used by Liu *et al.* is especially intriguing and signifies a new direction in the field of drop impact. Their study also introduces a novel method for reducing the contact time of millimetre-sized drops to values that had previously been considered impossible. Hence, their work complements and extends a recent approach by Bird *et al.*[9], who designed a surface in such a way that an impacting drop can split into two child drops that bounce off about 40% faster than the parent drop. Both studies[6,9] nicely show that clever surface structuring offers unexpected scenarios and challenges in the search for a lower limit for the contact time in drop bouncing. ❒

Doris Vollmer and Hans-Jürgen Butt are at the Max Planck Institute for Polymer Research, Ackermannweg 10, 55128 Mainz, Germany.

e-mail: vollmerd@mpip-mainz.mpg.de; butt@mpip-mainz.mpg.de

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