DROPLET IMPACT NEAR A MILLIMETER-SIZE HOLE

Rianne de Jong[* a)], Oscar R. Enriquez[*] & Devaraj van der Meer[*]
[*]*Physics of Fluids, Faculty of Science & Technology, University of Twente, Enschede, The Netherlands*

Summary When a water droplet impacts on a flat plate with a hole of millimeter size, sometimes a thin, fast jet is generated, which is markedly different from that originating from the drop's rebound. We argue that the hole is the direct cause for the jet. This is corroborated by the fact that the jet is produced during the spreading, and not the receding, phase of the droplet. Varying the distance between hole and location of droplet impact, we show that it is essential that the droplet only partly covers the hole in order to generate a jet.

INTRODUCTION

Drop impact on solid surfaces leads to a wide variety of phenomena. A water droplet can completely rebound and form a jet on a super-hydrophobic surface [1], it can form a crown-shaped splash due to interaction with air [2], or it can splash when encountering an obstacle [3] or a pore [4] along the way. Recently, the study of drop impact on a granular medium has been given significant attention [5]. In this case, the impacting target combines the properties of a rough solid surface with deformability and permeability, making this a very rich problem.

We have observed that when a drop impacts onto a rough surface, sometimes a jet occurs that appears to be much smaller than the droplet diameter. Since these jets appear during the spreading of the droplet on the substrate, we conjecture that they are due to fluid rebounding out of small holes in the surface. In order to create a well-controlled setup to test this conjecture, we study experimentally the impact of a drop near a small hole in an otherwise smooth solid surface.

EXPERIMENTAL SETUP

Water drops are released to impact near a circular hole on a perspex plate. We investigated hole dimensions of varying diameter and depth. A syringe pump and a needle are used to create water droplets of diameter 3.0 ± 0.3 mm. Impact velocity is varied between 2.9 and 5.5 m/s and the location of the droplet is changed by moving the needle. The droplet impact is recorded with a high-speed camera (Photron SA1) from the side with a frame rate between 5000 and 10000 frames per second. In part of the experiments this side view was combined with a simultaneous bottom view using a second high-speed camera (Photron APX-RS, 5000 fps). For these runs, the radial distance between droplet and hole r_{DH} can be determined accurately.

RESULTS

In some cases the experiments show agreement with our expectations: impacting a droplet near a hole produces a jet while the droplet is still spreading. Two examples of this jet are provided in figures 1a and 1b, where it can be seen that the jet diameter is much smaller than that of the spreading droplet. The jet forms near the center of the spreading droplet and needs to be distinguished from the splash of figure 1d, which is a similar phenomenon created at the edge of the spreading droplet when it collides with the wall of the hole [4]. In other cases however no jet or splash is formed at all, and we observe an air bubble instead which may (partly) burst or sometimes may be drawn back in the hole (figure 1c).

To shed light onto this rich phenomenology, we examine the radial distance between the centers of the hole and droplet impact r_{DH}, which turns out to be of great importance in the jet formation. We define the dimensionless distance Δ as the difference of the sum of drop and hole radius (R_D+R_H) and the radial distance r_{DH} divided by the hole diameter $2R_H$: $\Delta = (R_H + R_D - r_{DH})/(2R_H)$. With this definition, the region $0<\Delta<1$ corresponds to a partly covered hole at the moment of drop impact. When Δ is negative, the drop falls next to the hole and when the dimensionless distance is larger than 1, the falling droplet fully covers the hole.

In the phase diagram of figure 2 we plot the hole volume versus the dimensionless distance: Most importantly, a jet is seen to form only when the impacting droplet partly covers the hole, i.e., in the region $0<\Delta<1$, and for the larger hole volumes which correspond to a depth larger than 1 mm. Splashes form when the droplet impacts at some distance from the hole wall (for $\Delta < 0$, as would be expected, but also for positive Δ). Air bubbles instead of jets are invariably observed when the falling droplet covers the hole completely, i.e., when $\Delta > 1$.

Our interpretation of the above is as follows: Jetting can happen when the downward falling liquid can enter into the hole and be deflected upwards again. When the falling droplet covers the hole completely, air is entrapped within the hole and will prevent the liquid from entering. In this case no jet will occur. On the other side of the spectrum, where the overlap between the falling droplet and the hole is small, hardly any liquid will flow into the hole, such that jet formation is unlikely. As a result only in the intermediate region jets may form, provided that the deflected liquid can leave the surface before it interferes significantly with the droplet spreading over the hole.

[a)] Corresponding author. Email: jong.riannede@gmail.com

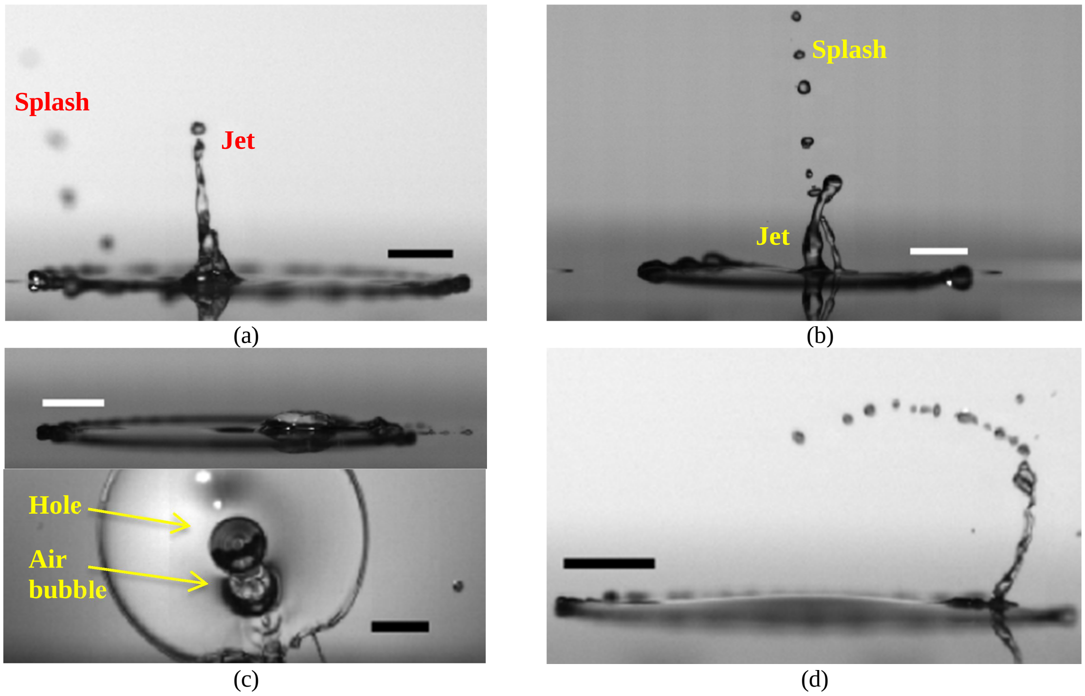

Figure 1. A droplet with a diameter of 3.0 mm impacts with a velocity of 2.9 m/s on a flat surface with a hole. Depending on the dimensionless parameter Δ, which characterizes the distance between the center of impact and that of the hole, different phenomena can occur. The bar in each picture represents 2 mm. (a) For Δ = 0.7 a jet is created at the center of the hole and a splash at the hole wall (side view). (b) We find similar features for the smaller value Δ = 0.4, but the jet appears to be weaker and the splash stronger (side view). (c) For Δ = 1.1 the droplet covers the hole completely, and an air bubble is formed. No jets and splashes are produced. (top image: side view, bottom image: bottom view). (d) For very small or negative values of Δ we only observe a splash caused by the hole wall (here Δ = 0.1, side view).

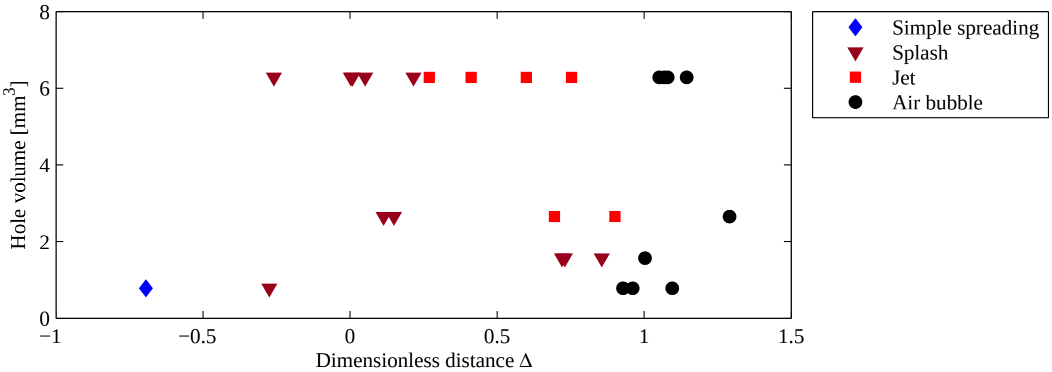

Figure 2. A phase diagram of the hole volume versus the dimensionless distance Δ, for a droplet impact velocity of 2.9 m/s. Between 0 and 1 the droplet is partly covering the hole, a value larger than 1 indicates the droplet is fully covering the hole and a negative value tells that the droplet is not falling directly into the hole.

CONCLUSIONS

We have shown that a jet can be created as the result of the interaction of a droplet impacting near a small hole. We characterized the jet formation by means of a dimensionless distance parameter Δ: The jet only appears when the drop impact partly covers the hole, as air needs to be able to escape. When the impacting droplet fully covers the hole, air is trapped inside the hole, which prevents the formation of the jet.

References

[1] Clanet C., Béguin C., Richard D., Quéré D.: Maximal deformation of an impacting drop. *J. Fluid Mech* **517**:199-208, 2004.
[2] Xu L., Zhang W.W., Nagel S.R.: Drop splashing on a dry smooth surface. *Phys Rev Lett* **94**:184505, 2005
[3] Josserand C., Lemoyne L., Troeger R., Zaleski S.: Droplet impact on a dry surface: triggering the splash with a small obstacle. *J. Fluid Mech* **524**:47-56, 2005.
[4] Roisman I.V., Weickgenannt C.M., Lembach A.N., Tropea C.: Drop impact close to a pore: experimental and numerical investigations, *ILASS-Europe*, 2010, Brno, Czech Republic.
[5] Katsuragi H., Durian D.J.: Unified force law for granular impact cratering. *Nat Phys.* **3**:420-423, 2007