Project-III Team Gamma

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[Introduction]

Water splash is happening everywhere in our daily life. It is one of the most common and also difficult physics phenomena to capture since it happened so fast and disappeared only in seconds. With the development of high speed imaging technology, people have been studied and captured beautiful photos and discovered amazing physics in water / liquid splash.

For project III, we are dropping dye into milk and water surface, pictures of water splendid and dye diffused in milk after droplet immersion are captured. The followed photo is generated by Photoshop using two digital photos taken during the water dropping experiments. The bouncing water droplet ejected upwards to form a alien like little man watching toward the blossom or fire worked sky. The whole presented a Sci-Fi feeling with Chinese water coloring style paint.

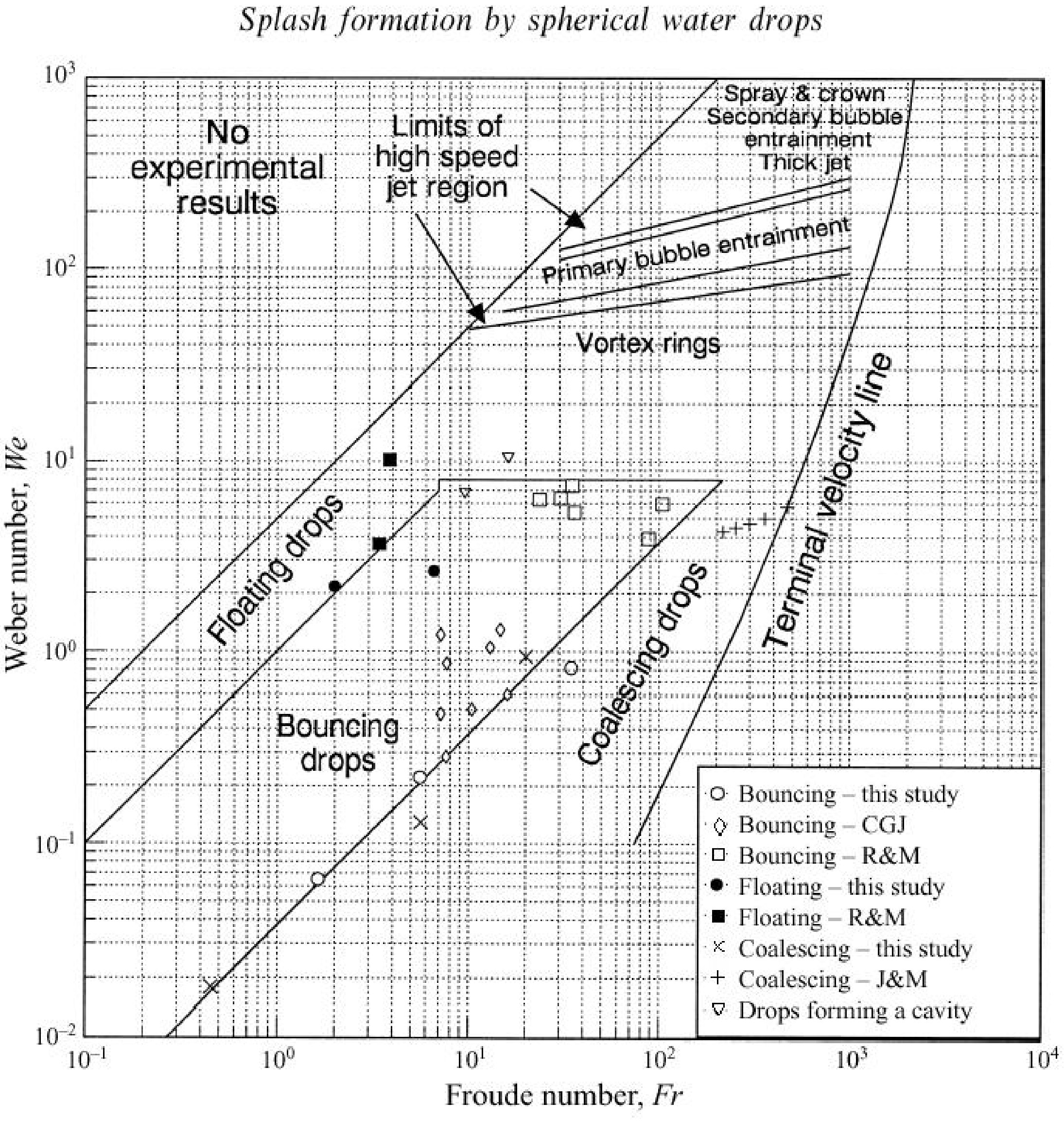
[Water splendid physics]

LIOW JONG LENG [1] has done an extensive research and reviews on "Splash formation by spherical drops". For liquids with low viscosities such as milk or water, the impact of a liquid drop involves a number of phenomena which are primarily determined by the Weber (We =ρdu^2/σ) and Froude (Fr = u^2/gd) numbers 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 (Rodriguez & Mesler 1985). Cresswell & Morton (1995) showed that during the initial stages of impact, the target liquid rises up the impacting drop. Capillary waves are propagated up the impacting drop as well as away from the impact site. A small cavity is formed and a wave swell appears at the edge of the cavity. The cavity collapses with more capillary waves propagating outwards. As the impact velocity increases, the cavity collapses to form a central jet with splash droplets. A vortex ring, first studied in detail by Chapman & Critchlow (1967), is formed and travels into the bulk liquid; the depth of travel depends on the impact velocity. Rodriguez & Mesler (1985) suggested that drops that splash do not form vortex rings and showed that a boundary between splashing and vortex ring formation occurred at a Reynolds number near 3000 for Froude numbers ranging from 16 to 400. Hsiao, Lichter & Quintero (1988), using their own data for mercury drops (Reynolds number of 20 000) and that of Rodriguez & Mesler (1985), suggested that an upper limit to the formation of vortex rings that follows drop impact is a Weber number of 64 and not dependent on the Reynolds number. Cresswell & Morton (1995) argued that the boundary condition on the viscous stress at the free surface is sufficient to account for enough vorticity to result in vortex ring formation. As the Weber number does not include viscosity, Cresswell & Morton used a force balance between the surface tension and pressure generated by drop impact and obtained a value for the upper limit of the Weber number.

In a series of experiments on 2.3 mm diameter water drops, Rein (1996) found that 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. Rein noticed that the entrapment of bubbles did not always accompany the formation of the thin high-speed jet and concluded that small disturbances acted to suppress bubble entrapment. Pumphrey & Elmore (1990) showed that the bubble entrapment regime had an upper and lower boundary on the (We, Fr)-plane. The upper limit could be a balance between the even spread of the drop over the surface of a hemispherical cavity and a surface tension restoring force. They obtained We ~ Fr^0.25 which fitted the experimental data of Pumphrey & Elmore (1990).

Pumphrey & Elmore (1990) observed a capillary wave which travels down the sides of the crater. When this wave reaches the bottom of the crater, its crest closes in from all sides, thus trapping the bubble'. OP(I) argued that “Whether a bubble is entrapped or not is determined by a delicate balance between the times at which the outward motion of the crater walls is reversed at different positions”. They reasoned that the time to maximum growth of the crater scales proportionally to drop diameter times the drop velocity to the third power, based on experimental observation by Pumphrey (privately communicated to OP(I)). Relating this to the time for a capillary wave formed at the bottom of the cavity to reverse its motion, they obtain the lower limit for bubble entrapment as We~Fr^0.2. Although the relationship fitted the experimental results well, their boundary integral simulation of the bubble entrapment for drops falling at terminal velocity indicated that the bubble entrapment envelope was larger than that found from the experimental results (Oguz & Prosperetti 1991).

The regime above the bubble entrapment regime is characterized by cavity collapse to form a thick jet where one or two large drops are detached with a low velocity and the sides of the cavity form a crown which breaks up to form small splash drops (Worthington 1908; Edgerton & Killian 1954). At even higher velocities (Engel 1966), the cavity formed is hemispherical in shape and the crown that develops rises high enough to lose its momentum so that surface tension pulls it inwards to form a canopy over the cavity. This canopy meets at the centre and a weak jet is ejected upwards and a stronger jet ejected downwards. The downward jet halts the rise of the thick central jet formed from the cavity collapse. The central jet normally does not break through the canopy. L.J. LENG summarized the droplet impact phenomena in We~Fr plane as above [1].



[Principles of perceptions]

Dyed water droplet is prepared. Surface liquids are water and milk. While dyed droplets fall into milk surface, the food coloring can be easily diffused into milk and water to make the splendid distinguishing and colorful.

[Experimental setup]

Water is dropped from a foot high to the glass cup or container filled with water or milk. Assuming surface tension $\sigma=72.8$ dyne/cm, density $\rho=1$ gram/cc, gravity $g=9.81$ m/s^2, distance $h=30$ cm (~ 1 foot), and diameter of water droplet is around 0.5 cm.

The time of water droplet travel is $t=(2h/g)^{0.5}=0.25$ sec.
Impact velocity $u=gt=245$ cm/sec
Weber number = $\rho du^{2}/\sigma = 443$
Froude number = $u^{2}/gd = 131.5$

Comparing to the We-Fr plane above, the droplet is characterized by cavity formed a hemispherical shape and the crown that develops rises high enough to lose its momentum so that surface tension pulls it inwards to form a canopy over the cavity. This canopy meets at the centre and a weak jet is ejected upwards and a stronger jet ejected downwards. The downward jet halts the rise of the thick central jet formed from the cavity collapse.

[Camera setup]

Two photos are used in Photoshop to combine the picture.
[1] Water droplet in glass cup
Nikon D200 2007/12/09 17:45:42.5
Image Size: Large (3872 x 2592)
Focal Length: 60mm
1/200 sec - F/8 - ISO 400
Exposure Comp.: +0.3 EV
Size of view ~ 15 cm x 10 cm
[2] Dye diffused in milk
Nikon D80 2007/12/09 17:11:10.1
Image Size: Large (3872 x 2592)
Focal Length: 135mm
1/30 sec - F/5.6 - ISO 400
Size of view ~ 20 cm x 13 cm

[Photoshop work]

1. The glass cup with water droplet is cut to place at the left bottom corner with same background all over.
2. Dye diffused milk is cropped into appropriate rectangular to get rid of metal container. Three of the image is reproduced and managed into the picture. One is in original color and blend in “Difference” mode with 84% opacity, the second is flip horizontal and blend in “Luminosity” mode with 91% opacity, and last one is blend in “Linear light” mode with 85% opacity.

[Summary]

One of the most visible and common fluid phenomena-water splashes is captured in digital camera. The experiment is done by dropping dye from 30 cm high to a glass of water and milk. The Weber number ~ 443 and Froude number ~131.5 shows it's a comparatively high speed dropping. It shows droplet impacts created a cavity with a hemispherical shape and the crown that develops rises high enough to lose its momentum so that surface tension pulls it inwards to form a canopy over the cavity. This canopy meets at the centre and a weak jet is ejected upwards and a stronger jet ejected downwards. The downward jet halts the rise of the thick central jet formed from the cavity collapse.

[Reference]

[1] LIOW JONG LENG, J. Fluid Mech. (2001), vol. 427, pp. 73~105.