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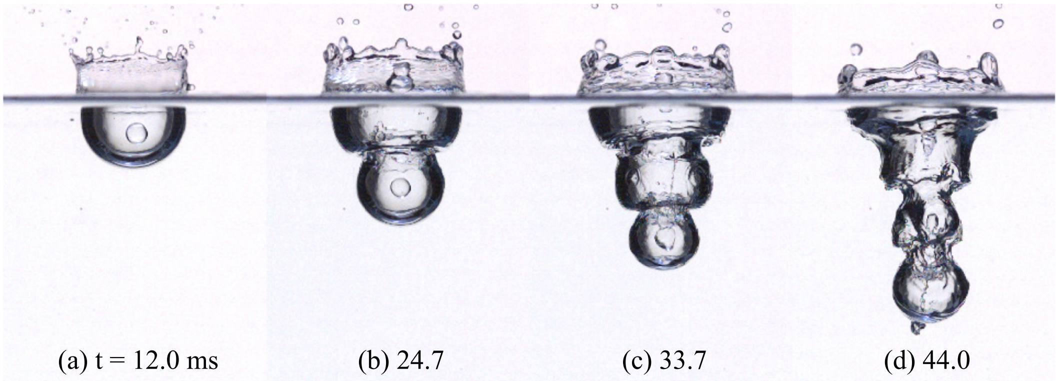

FIG. 1. Images representing four time steps of a droplet stream impacting a water surface with $t = 0$ corresponding to free-surface impact of the first droplet. The first droplet creates a hemispherical subsurface cavity with a second droplet seen inside (a). The second droplet has now impacted the bottom of the initial cavity, forming a secondary cavity and a third droplet can be seen falling through (b). The third and fourth droplets impact the cavity further down extending the cavity length and creating four nested cavities (c) and (d). http://gfm.aps.org/meetings/dfd-2014/54174c1769702d585cf40200.

Matryoshka cavity

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When a water droplet impacts a free surface with sufficient velocity, the momentum transfer results in the formation of a hemispherical cavity expanding radially from the point of impact.[1] This cavity continues to expand until the kinetic energy is completely converted to potential energy (Fig. 1(a)).[2] Pumphrey and Elmore equated the potential energy of this subsurface cavity with the kinetic energy of the impacting droplet, concluding that the magnitude of the cavity radius is proportional to impact velocity and droplet diameter.[3]

Less is known about the effect of several droplets impacting a water surface in rapid succession. The first impacting droplet creates a subsurface cavity as described above; the second droplet creates a very similar result, but with the cavity initiating from the base of the first (Fig. 1(b)). A third droplet and a fourth droplet expand the depth and compound nature of the cavity in Figs. 1(c) and 1(d). We refer to the nested cavity shape formed in the wake of multiple droplets as a matryoshka cavity (named after Russian nesting dolls). This phenomenon is only observed when a series of droplets impacts a free surface with a sufficiently high temporal frequency such that subsequent cavities form before the initial cavity closes. One may be inclined to conclude that the ideal droplet frequency should involve a droplet impacting just as the previously formed cavity has reached its apogee. However, this would result in the lower portions of this complex cavity forming as the upper levels collapse. We conjecture that the ideal frequency is higher than this definition, allowing the top of the cavity to continue to expand outward while the bottom is extending downward. Of course, the upper bound on droplet frequency would be the case where the droplets are so close together that they coalesce to form a single jet, which results in a different impact event.

As we approach this ideal impact frequency, larger compound cavities can be formed, extending much deeper below the free surface and lasting longer than a cavity generated from a single droplet impact. Rather than producing the spherical cavity observed by Worthington, a droplet

FIG. 2. A stream of pink-colored droplets impacts a water surface, forming a series of nested cavities that combine to form a matryoshka cavity. http://gfm.aps.org/meetings/dfd-2014/54174c1769702d585cf40200.

stream produces a long conical cavity. Fig. 2 presents an extensive cavity formed by approximately 15 droplets impacting the water surface in succession, and is approximately 14 times deeper than a cavity created by a single droplet. It is likely that this image does not represent the upper limit of the cavity proportions that can be achieved.[4]

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