

Void Collapse and Jet Formation: The impact of a disk on a water surface.

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Void formation occurs in a large number of real world impact phenomena, ranging from the familiar rain droplets falling into puddles to such large-scale phenomena as asteroids impacting on planets [1]. The large impact velocities of asteroids, typically of the order of ~ 12 km/s, induce stresses far beyond the point at which any material will yield. In [2] we studied the impact of a steel ball on very fine, soft sand. Here we analyze the impact of a disc on a flat water surface. The formation and collapse of the void created during the impact, is studied both experimentally and numerically.

In the experiments, a disk of radius R is pulled down into a water tank by means of a linear motor. The motor allows for precisely controlled constant velocities of the disk, ranging from $U = 0$ to 5 m/s. The presence of the free surface and the short duration of the phenomenon suggest that the effects of viscosity can be neglected during the formation and collapse of the void. An inviscid model can therefore be adopted, which is efficiently solved numerically by means of a boundary integral method. Figure 1 shows that the simulations are in excellent agreement with the experimental void formation and collapse. As can be seen in Figure 2, the depth of the void closure divided by the disk radius d_s/R scales with the square root of the Froude number, defined by $Fr = U^2/gR$, for both experiments (blue error bars) and simulations (red dots).

As the walls of the void come together on the axis of symmetry at the end of the collapse, the destruction of the radial liquid momentum produces a large pressure spike which creates two jets of water, one shooting up straight into the air (Figure 3a), and one down, piercing the void enclosed by the collapse (Figure 3b).

[1] H.J. Melosh, *Impact Cratering: A Geologic Process* (Oxford University Press, Oxford, 1989)

[2] D. Lohse, R.P.H.M. Bergmann, R. Mikkelsen, C. Zeilstra, D. v/d Meer, M. Versluis, K. v/d Weele, M.A. v/d Hoef, J.A.M. Kuipers - *Impact*, preprint (2004)

[3] S. Gaudet - *Numerical simulation of circular disks entering the free surface of a fluid*, Phys. Fluids **10**, 2489 (1998)

[4] J.W. Glasheen, T.A. McMahon - *Vertical water entry of disks at low Froude numbers*, Phys. Fluids **8**, 8 (1996)

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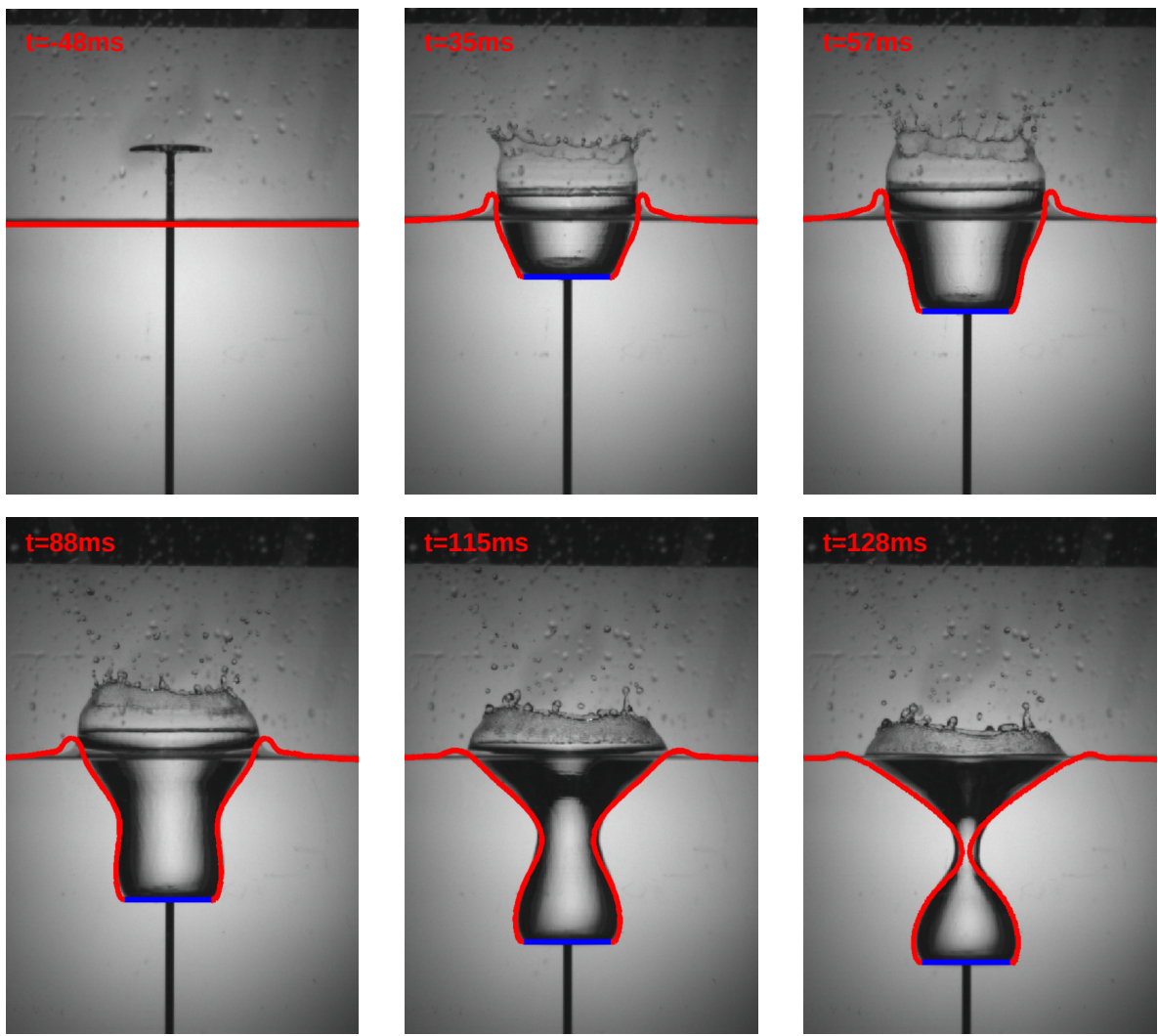


Figure 1: Snapshots from the formation and collapse of the void in an experiment in which a linear motor pulls down a disk of radius $R = 3.0$ cm through a water surface at a constant velocity $U = 1.0$ m/s. The overlaying blue/red lines are the numerical results from the boundary integral simulation using the same initial conditions as in the experiment. As can be seen, experiment and simulation are in very good agreement.

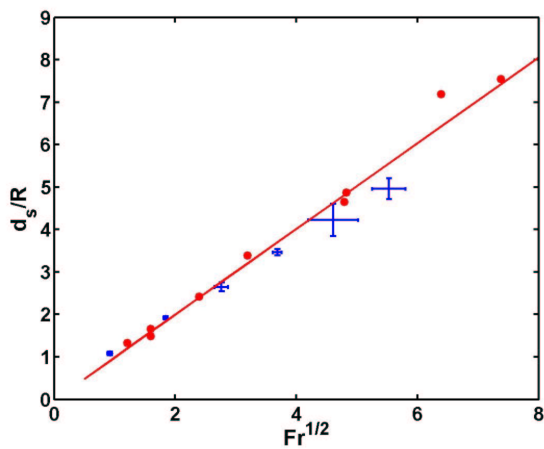


Figure 2: A clear $Fr^{1/2}$ scaling law for d_s/R is observed for experiments (blue error bars) and simulations (red dots).

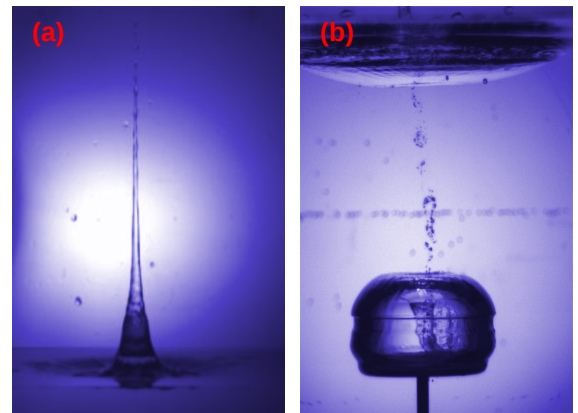


Figure 3: After the collapse of the void (Figure 1) an upward jet (a) shoots straight into the air, and a downward jet (b) pierces the enclosed void.