Air bubble entrainment at liquid drop impact

W. Bouwhuis, R. C. A. van der Veen, T. Tran, I. R. Peters, D. van der Meer, J. H. Snoeijer, C. Sun, & D. Lohse *

The air bubble entrainment under a droplet impacting on a plane surface is studied both experimentally, numerically, and theoretically. The origin of the bubble entrainment is the air pressure buildup under the droplet just before impact, which leads to a dimple-shaped droplet and thus to subsequent air bubble entrapment. By employing high-speed color interferometry, we experimentally obtain the dimple profiles as function of the impact velocity. These are compared to dimple profiles from numerical simulations, which combine boundary integral simulations of the liquid with a lubrication approximation of the air layer under the falling droplet.

For large impact velocity our results are consistent with scaling laws by S. Mandre, M. Mani, and M.P. Brenner, J. Fluid Mech. 647, 163 (2010), who predict that the dimple height and bubble volume scale as $\sim R \ St^{2/3}$ and $\sim R^3 \ St^{4/3}$, respectively, where $St$ is the (inverse) Stokes number defined as $St = \eta_g/(\rho_l U R) = Re^{-1} \rho_g/\rho_l$. Here, $U$ is the impact velocity, $R$ the droplet radius, $\eta_g$ the dynamic viscosity of the gas, and $\rho_l$ and $\rho_g$ the densities of the liquid and gas, respectively.

For small impact velocities, however, we observe deviations from these scaling laws, pointing towards a regime where the air pressure is balanced by surface tension rather than by inertia. We derive the respective scaling laws in this regime, finding $\sim R \ St^{-1/2}$ for the dimple height and $\sim R^3 \ St^{-1}$ for the bubble volume. The immediate consequence is that the volume of the entrained bubble has a maximum as function of the impact velocity of the impacting droplet, or as a function of the impact height. For a millimeter water droplet the optimal impact height for maximal air entrainment turns out to be a few millimeters.

To experimentally verify our findings we perform various impact experiments with varying droplet velocities: Indeed, we can experimentally confirm that there is an optimal impact velocity for maximal bubble entrainment.

*Physics of Fluids Group, University of Twente, PO Box 217, 7500 AE Enschede, The Netherlands

Figure 1: (a) Schematics of the experimental setup. (b) Example of an interference pattern and the extracted air thickness profile. (c) Schematics of the air film between the drop and the glass slide. The dimple profile $H(r, t)$ is the main object of interest. It results into an air bubble entrainment.