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Events before droplet splashing on a solid surface

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A high-velocity ($\approx 1\,\mathrm{m\,s^{-1}}$) impact between a liquid droplet ($\approx 1\,\mathrm{mm}$) and a solid surface produces a splash. Classical observations traced the origin of this splash to a thin sheet of fluid ejected near the impact point, though the fluid mechanical mechanism leading to the sheet is not known. Mechanisms of sheet formation have heretofore relied on initial contact of the droplet and the surface. In this paper, we theoretically and numerically study the events within the time scale of about 1 μs over which the coupled dynamics between the gas and the droplet becomes important. The droplet initially tries to contact the substrate by either draining gas out of a thin layer or compressing it, with the local behaviour described by a self-similar solution of the governing equations. This similarity solution is not asymptotically consistent: forces that were initially negligible become relevant and dramatically change the behaviour. Depending on the radius and impact velocity of the droplet, we show that the solution is overtaken by initially subdominant physical effects such as the surface tension of the liquid–gas interface or viscous forces in the liquid. At low impact velocities surface tension stops the droplet from impacting the surface, whereas at higher velocities viscous forces become important before surface tension. The ultimate dynamics of the interface once droplet viscosity cannot be neglected is not yet known.

1. Introduction

At sufficiently high impact velocities, a droplet colliding with a solid surface produces a splash. The commonality of splashing of droplets belies the fact that there is another potential solution to the equations of fluid mechanics for the impact of droplets on a solid surface, that the droplet simply spreads smoothly outwards along the surface. Several studies (Gopinath & Koch 2002; Bach, Koch & Gopinath 2004; Pan & Law 2007) have studied the approach of a droplet at low to moderate velocities where surface tension dominates and a plethora of phenomena such as droplet bouncing are observed. Here we are investigating a different parameter regime, and our goal is to have a better understanding of the explosive phenomena of splashing.

Why does splashing occur? Bowden & Field (1964), Jenkins & Booker (1960), Lesser (1981), Field, Dear & Ogren (1989) and Lesser & Field (1983) discovered that when a splash occurs, a thin fluid sheet is emitted very near the point at which the droplet contacts the solid surface, with the sheet subsequently breaking down into a spray of droplets. Figure 1 shows a snapshot of a sheet (Xu, Zhang & Nagel 2005), which has been ejected into the gas before disintegrating into satellite drops; the sheet generation occurs much earlier in the impact process. Although known for nearly half

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