Test-Case number 16: Impact of a drop on a thin film of the same liquid (PE, PA)

F. Pigeonneau, Saint-Gobain Recherche, BP 135 - 39 quai Lucien Lefranc
F-93303 Aubervilliers cedex, France
Phone: +33 (0)1 48 39 59 99, Fax: +33 (0)1 48 39 58 78
E-Mail:*franck.pigeonneau@saint-gobain.com*

F. Feuillebois, PMMH, UMR 7636 CNRS, ESPCI, 10 rue Vauquelin
75231 Paris cedex 05, France
Phone: +33 (0)1 40 79 45 53, Fax: +33 (0)1 40 79 47 95
E-Mail: *francois.feuillebois@espci.fr*

1 Practical significance and interest of the test case

Various physical phenomena may occur following the impact of a drop, depending on the target and physical conditions. This test case is limited to the impact of a drop on a thin film of the same liquid. This problem has a number of applications, e.g. in chemical engineering (coating, cooling by drops, erosion by drops, painting, etc.), material processing (welding, etc.), agriculture (dispersion of products in fields, etc.).

The purpose of the present test case is to compare numerical results to existing experimental ones. As described by Levin & Hobbs (1971), Cossali *et al.* (1977) and Cossali *et al.* (1991), the impact of a drop on a thin film consists of several steps: formation of a crown and jetting, instability of the crown and formation of jets which themselves form secondary droplets. Pictures reproduced from Cossali *et al.* (1977) are presented in figure 1. We will limit ourselves here to study the formation of the crown and its growth with time, as shown essentially by the first three pictures in figure 1.

2 Definitions and physical model description

Let d be the drop diameter and d_c be the crown diameter. Let U be the drop impact velocity. Let h be the height of the liquid film. Consider the following experiments from Levin & Hobbs (1971) and Cossali *et al.* (1977), using water in both cases:

	d (mm)	h (mm)	U (m/s)
Levin & Hobbs (1971)	2.9	0.5	4.8
Cossali *et al.* (1977)	5.1	0.5	2.14

Let ρ be the mass density of the liquid and σ its surface tension. Note that the Weber number defined by:

$$\mathrm{We} = \frac{\rho U d}{\sigma}$$

is of the same order of magnitude for both cases. The value of U for Cossali *et al.* (1977) was derived from their data that $\mathrm{We} = 320$ in their case, using the standard values $\rho = 10^3\, kg/m^3$ and $\sigma = 7.3 \times 10^{-2} N/m$. The Ohnesorge number

$$\mathrm{Oh} = \frac{\mu}{\sqrt{d\sigma\rho}},$$

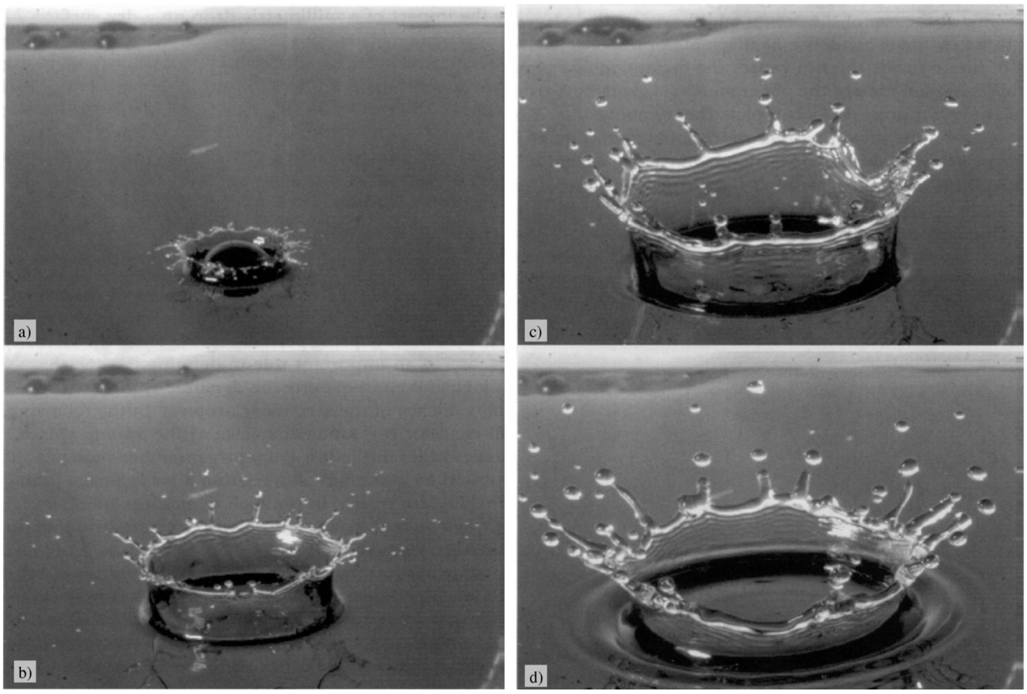

Figure 1: Evolution of the crown for a drop impact onto a thin liquid film. From Cossali *et al.* (1977).

where μ is the fluid dynamic viscosity, is also of the same order for both cases, so that as explained in Cossali *et al.* (1977) the phenomena are expected to be similar for both experiments. Moreover, the relative height of the film is also of the same order for both cases. Based on these ideas, we plotted the results for the evolution of d_c with time τ from Levin & Hobbs (1971) and Cossali *et al.* (1977) in dimensionless variables, using:

$$D_c = \frac{d_c}{d}, \qquad t = \frac{\tau U}{d}.$$

It is observed in figure 2 that both sets of experiments superimpose. We also plotted in the same figure the square root law $D_c \sim \sqrt{t}$ proposed by Yarin & Weiss (1995) from their numerical simulation assuming an inviscid fluid. Note that the numerical simulation of Josserand & Zaleski (2003) which includes viscosity effects also gives a $D_c \sim \sqrt{t}$ behavior. As seen in figure 2, a power law of the form $D_c \sim t^{0.38}$ fits better all experimental results. In later experimental results, Cossali *et al.* (1991) defined several crown diameters, viz. upper, lower, inner, outer and measured their time evolution. They also remarked that attempts to fit the whole experimental data with the model of Yarin & Weiss (1995) were not successful. Instead, they found for all crown diameters a law of the form $D_c \sim t^n$, where n is around 0.4, that is similar to the results mentioned above. Correlating some experimental point of Thoroddsen (2003) for the radial deceleration of the sheet (his figure 3(b)) gives $dD_c/dt \sim t^{(-0.65)}$, consistent the preceding results.

There are not so many results concerning the height of the crown. The maximum height of the crown was measured for various liquids by Macklin & Metaxas (1976) and the ratio of the crown height H to the crown radius $R_c = d_c/2$ is plotted versus the Weber number based on the drop radius Wb=We/2 in figure 3. The case of a shallow liquid is of interest here. Cossali *et al.* (1991) find a law $H/R_c \sim Wb^m$, where m is about 0.65 to 0.75.

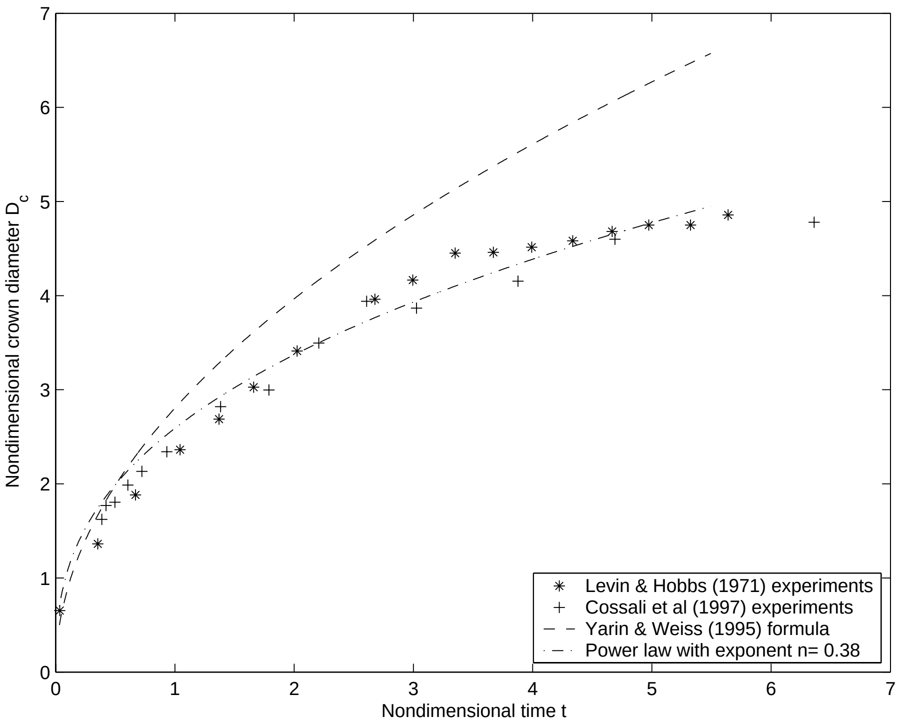

Figure 2: Time evolution of the crown diameter, in dimensionless variables. Experiments by Levin & Hobbs (1971) and Cossali *et al.* (1977); square root law from the model of Yarin & Weiss (1995) and fitted power law $D_c \sim t^{0.38}$.

3 Test-case description

The calculation will concern the impact of a drop of liquid on a thin film. Typically, water will be considered, with drop diameters and velocities of the order of the experimental data given in the table. A challenge is to model the experimental results for the time evolution of the crown diameter which follows an empirical law of the type $D_c \sim t^n$, where n is close to 0.4 rather than the value 0.5 obtained in Yarin & Weiss (1995) and Josserand & Zaleski (2003).

Then comparison with the experimental data for the crown height (figure 3 from Macklin & Metaxas (1976)) and Cossali *et al.* (1991)) may be tried, for various liquids.

Note that this test case also suggests that more experiments are needed.

References

Cossali, G.E., Coghe, A., & Marengo, M. 1977. The impact of a single drop on a wetted solid surface. *Experiments in fluids*, **22**, 463–472.

Cossali, G.E., Brunello, G., Coghe, A., & Marengo, M. 1991. Impact of a single drop on a liquid film: experimental analysis and comparison with empirical models. *Proc. Italian Congress of Thermofluid Dynamics UIT, Ferrara, 30 June - 2 July.*

Josserand, C., & Zaleski, S. 2003. Droplet splashing of a thin liquid film. *Phys. Fluids*, **15**(6), 1650–1657.

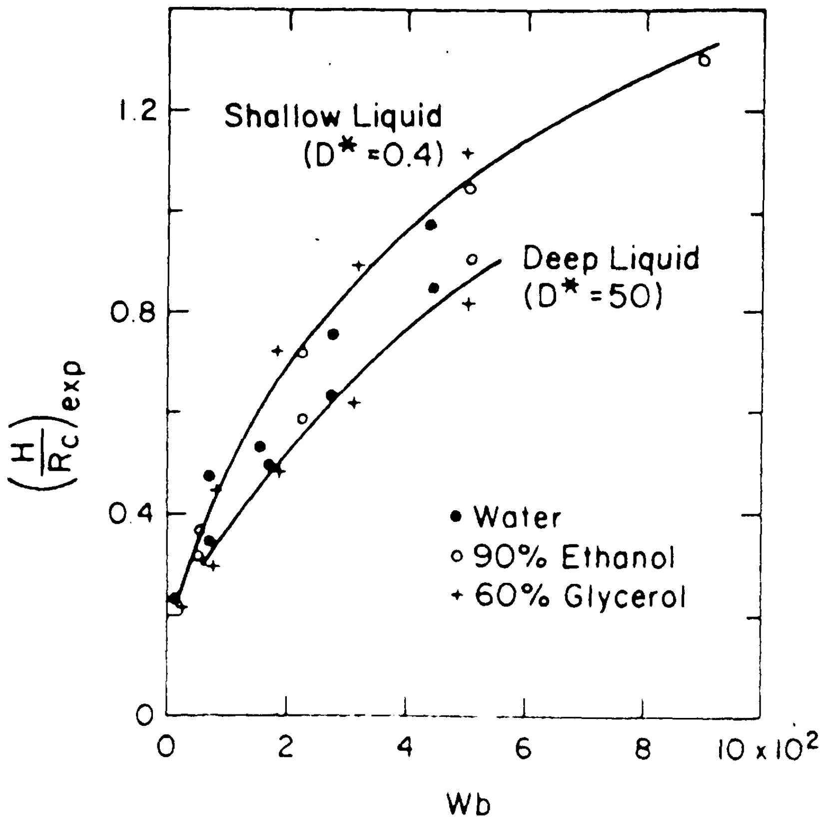

Figure 3: Evolution of the dimensionless crown height from Macklin & Metaxas (1976). Here, $D^* = h/R_c$.

Levin, Z., & Hobbs, P.V. 1971. Splashing of water drops on solid and wetted surfaces: Hydrodynamics and charge separation. *Phil. Trans. R. Soc. A*, **269**, 555–585.

Macklin, W.C., & Metaxas, G.J. 1976. Splashing of drops on liquid layers. *J. Appl. Phys.*, **47**(9), 3963–3970.

Thoroddsen, S.T. 2003. The ejecta sheet generated by the impact of a drop. *J. Fluid Mech.*, **451**, 373–381.

Yarin, A.L., & Weiss, D.A. 1995. Impact of drops on solid surfaces: Self-similar capillary waves and splashing as a new type of kinematic discontinuity. *J. Fluid Mech.*, **283**, 141–173.