Acoustic effects on the deformation dynamics inside droplets hit by a laser

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The impact of a nanosecond laser pulse onto a liquid droplet can induce a strong deformation and propulsion of the droplet. This concept has an important application in Laser Produced Plasma (LPP) light-sources used for nano-lithography. In these sources a nanosecond laser pulse hits a micrometer sized droplet with the sole purpose of creating flat liquid sheet. Fundamental understanding of the sheet formation is a must for developing more powerful LPP-EUV light sources. Previous studies show that the laser impact onto a liquid droplet can be accurately modeled as a one-sided pressure pulse applied on the liquid-vapor interface of the droplet [1, 2].

In this study, we aim to understand the droplet deformation in a regime where the duration of the pressure pulse is short, i.e. of the order of the timescale on which pressure waves travel through the droplet. In this regime we expect the deformation dynamics to differ from incompressible modeling [3], since the pressure field inside the droplet has not yet been fully developed.

To this end, we developed an analytical model to study the the pressure waves inside the droplet based on a perturbation analysis of the Navier-Stokes equations in the weakly compressible regime. Figure 1 shows a contour plot of the pressure field inside the droplet for a uniform beamprofile at three different timestages. We show theoretically that when the duration of the pressure pulse is long, existing incompressible models accurately describe the droplet deformation dynamics [3]. However when the duration of the pressure pulse is short compared to the timescale pressure waves travel trough the droplet, the pressure field inside the droplet has not yet been established and the expansion dynamics of the droplet is altered.

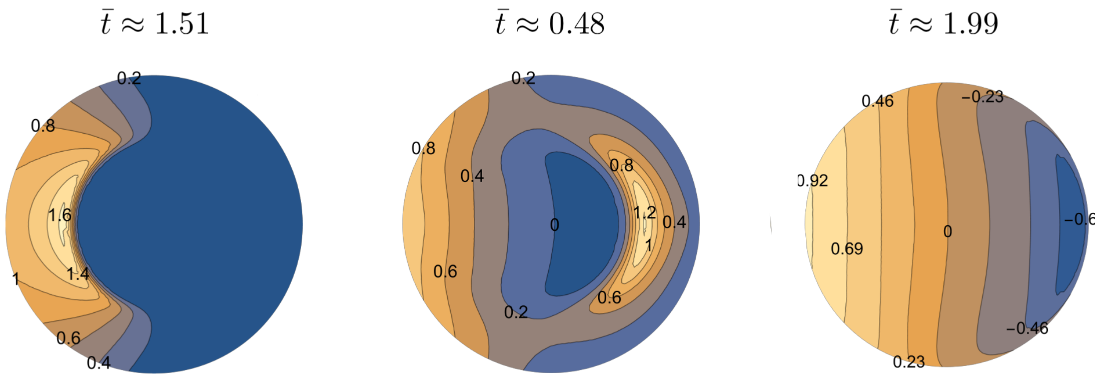

Figure 1: The spatiotemporal pressure field inside a droplet hit by a uniform laser profile for different timestages. All times have been scaled by the acoustic timescale R_0/c, where R_0 is the initial droplet radius and c is the speed of sound inside the droplet. In this example, the pressure-pulse on the gas-liquid interface of the droplet lasts much longer than the acoustic timescale.

References

[1] Klein, A.L., Bouwhuis, W., Visser, C.W., Lhuissier, H., Sun, C., Snoeijer, J.H., Villermaux, E., Lohse, D., Gelderblom, H. Phys. Rev. Applied 3, 044018, 2015

[2] Kurilovich, D., Klein, A.L., Torretti, F., Lassise, A., Hoekstra, R., Ubachs, W., Gelderblom, H. and Versolato O. O. arXiv:1604.00214

[3] Gelderblom, H. Lhuissier, L., Bouwhuis, W., Lohse, D., Villermaux, E., Snoeijer, J.H., Journal of Fluid Mechanics, 794, pp 676-699 doi:10.1017/jfm.2016.182