Impingement of Single Droplets on a Dry Smooth Surface at high Weber Numbers

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Abstract

The impingement of single water droplets on a smooth dry surface was experimentally investigated. A glass substrate was mounted on a rotating flywheel in order to obtain high impact velocities and high Weber numbers, respectively. Five different Weber numbers were observed by means of shadowgraphy technique: We $= 1000$, We $= 5000$, We $= 10000$, We $= 20000$ und We $= 30000$. The outcome of the measurement was analysed by digital image processing to quantify the distribution of the diameter of the resulting secondary droplets. This distribution of the droplet diameter is influenced by the Weber number and time during the impingement process.

Introduction

The impingement of droplets on solids surface is important for a wide range of technical applications like internal combustion engines, cooling, surface coating and ink jet printing. In many studies the influence of the Weber number (We) and the choice of fluid-substrate-combination on the outcome of a droplet impact was investigated [1, 2]. Those studies usually deal with small or medium Weber numbers, where the impact-scenario splashing already occurs. In [3] the footprint of the splashing impact of droplets at high Weber numbers is compared with the result of a mathematical model based on the linear Rayleigh-Taylor instability for the purpose of specifying the wavelength of the perturbation around the impinging droplet.

The aim of the current investigation was to determine the diameter distribution of secondary droplets after the impact and the overall volume of fluid which is lost to the surrounding air after the impact. Both quantities were identified to be depended on the Weber number.

Materials and Methods

To achieve high Weber numbers an apparatus was built moving a surface relative to the falling drop. For this a flywheel of 0.6 m diameter was constructed (see fig. 1). In [3] it is emphasised that the additional forces due to the rotational movement of the substrate, centrifugal and Coriolis, may be neglected if the droplet diameter is small relatively to the radius of the impingement position. This is the case in the current examination.

The apparatus allows the variation of the resulting Weber number by changing the rotational speed ω of the flywheel and phase-locked imaging of the substrate. Weber numbers up to We $= 30000$ are generated depending on the fluid used and the diameter of the droplets. The resulting Reynolds numbers are small at the same time. Glass was chosen as the substrate and it was made hydrophilic by open flame treatment. This allows for the reproducible quality of the surface. For future investigations the substrate material may be easily changed.

In the present study the impact of droplets at five different impact velocities v_i was observed: ($5.4\,\mathrm{m{\cdot}s^{-1}}$, $11.7\,\mathrm{m{\cdot}s^{-1}}$, $16.6\,\mathrm{m{\cdot}s^{-1}}$, $23.0\,\mathrm{m{\cdot}s^{-1}}$, and $28.3\,\mathrm{m{\cdot}s^{-1}}$). The droplets are produced by a droplet on demand generator, their diameter was $D_d = (2.75 \pm 0.1){\cdot}10^{-3}$ m. The droplets fell under the influence of gravity.

For the shadowgraphy measurements, a double-frame LaVision ImagerPro hs high-speed camera was used to record the impact. To provide uniform high intensity and short back-lighting, a double-pulse Litron Nd:YAG laser was used. To widen the laser beam and to avoid speckle, a LaVision Diffuser Optics was mounted between the laser and the substrate. Due to the fluorescence of the Diffuser Optics, the duration of the illumination flash was 20 ns.

Using the LaVision Software ParticleMaster, always double-frame images where taken for determination of the correct impingement velocity of primary and secondary droplets. This software was also used to calculate the droplets' diameter and their position on the image. These results were further processed in Matlab to evaluate the volume of the splashed secondary droplets in order to estimate the remaining volume on the surface. The full paper will show how this was done.

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Results and Discussion

In fig. 2 the histogram of the secondary droplet's size for $\mathrm{We} = 5000$ is depicted. It can be seen that the size of the secondary droplets changes during the impact process. With increasing temporal distance between release of the primary drop and the moment of photographing, the diameter distribution is shifted to larger secondary droplets. This may be caused by coagulation of small droplets. The distribution of the relative volume within the classes of size shows the same shift.

With growing Weber number the maxima of both distributions move to smaller droplets. Further more the volume distribution at high Weber numbers shows that the maximum of relative volume does not necessarily coincide with the maximum of the relative occurrence. Note that no droplets in the classes below $30 \cdot 10^{-6}$ m can be detected by the current system. This is due to the limited optical resolution, but by choosing a larger focal length of the lens, at high Weber numbers the secondary droplets would drop out of the field of view.

References

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[3] Mehdizadeh, N. Z., Chandra, S. and Mostaghimi, J., *Journal of Fluid Mechanics* 510: 353–373 (2004).

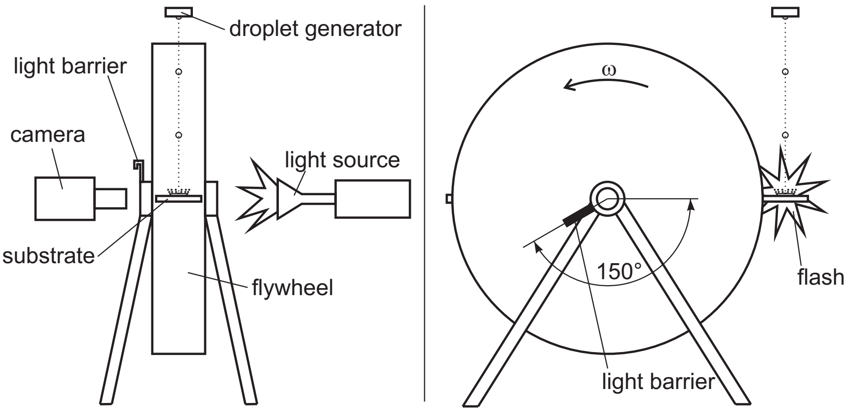

Figure 1. Set up of the flywheel

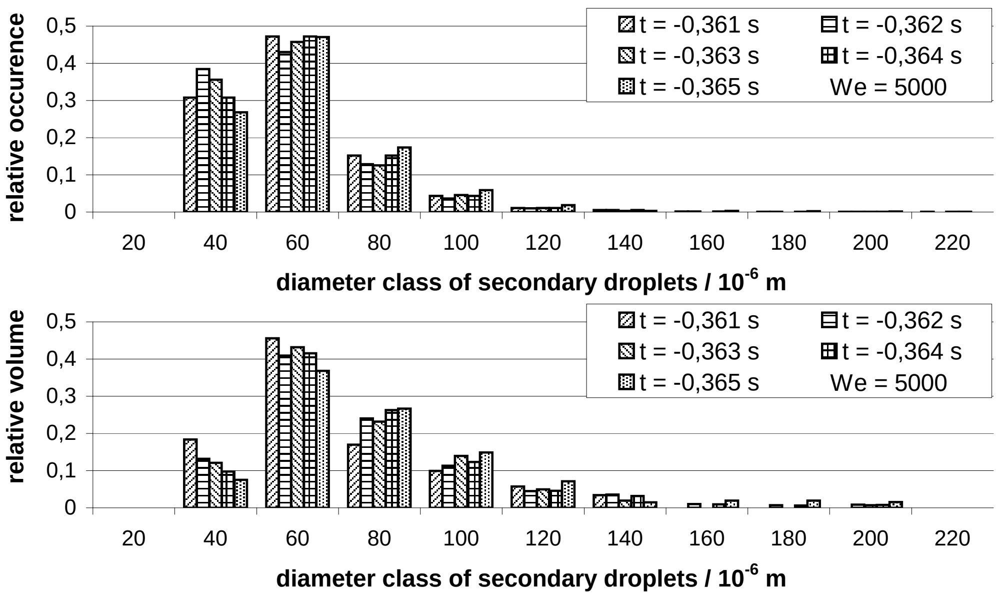

Figure 2. Top: Relative occurence of secondary droplet size during the impact, $\mathrm{We} = 5000$. Bottom: Relative Volume of secondary droplet size within the classes, $\mathrm{We} = 5000$.