Droplet surfing on a boundary layer

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There are numerous ways to achieve levitation of an object. In principle, the goal is to achieve the balance between the gravitational force and the lift force acting upon an object. One way to levitate an object is to place it in a vertical or inclined airstream. The other is to generate a standing acoustic wave and place an object in the node of a wave. Levitation can be realized in a wide range of temperatures. One famous example of high temperature levitation is the Leidenfrost effect described in 1756 by Johann Gottlob Leidenfrost. When a droplet of volatile fluid approaches a surface hot enough, the liquid starts to evaporate creating vapor film that prevents the droplet from the direct contact with surface. This results in severe decrease of heat flux between the surface and the droplet. Absence of adhesion forces between solid surface and liquid yields extreme mobility of a droplet. If the surface temperature is below the so-called Leidenfrost point, the liquid wets the surface and one can observe rapid process of boiling. The effect has been described thoroughly in [6]. Recently it has been shown that placing a droplet near a moving surface can result in similar behavior to the Leidenfrost effect. In contrast to Leidenfrost phenomenon, this occurs also at room temperatures. If we entrain a droplet of fluid onto a tangentially moving surface, and if the velocity is high enough, the drop starts to levitate. Above certain velocity threshold, a thin film of air slips under the drop and prevents the drop from wetting the surface. It turns out that the moving surface does not have to be solid. As presented in [1], a droplet placed on top of a hydraulic jump levitates on a thin film of air. The characteristic feature in this case is lack of translational movement. The droplet continuously rotates without coalescing with the same liquid.

The first levitation of a droplet on air boundary layer has been demonstrated in [4]. Levitation was obtained at inner side of a ring rotating with horizontal axis of rotation. The same aerodynamic effect has been considered by Gauthier et al. [2]. In this case, a flat disk was rotating with vertical axis of rotation. This fact results in spatial variation of velocity field. Depending on the deposition location, droplet experienced various forcing. The thickness of the gap between the drop and the solid surface increases with surface speed. The shape of the drop also changes as the velocity increases. Results presented in [2] were obtained in the laminar regime. The present work considers interaction of a droplet with turbulent boundary layer. Firstly, we characterize velocity field in the direct neighbourhood of the rotating disk. Following [5], we define Reynolds number as

$$Re = \frac{r^* \Omega^* L^*}{\nu} \tag{1}$$

where r^*, Ω^*, ν and L^* denote radius, angular velocity, kinematic viscosity and length-scale $L^* = (\nu/\Omega^*)^{1/2}$, respectively. We consider a flat disk with diameter of 20cm. The disk is mounted on the axis of an electric motor, which allows to obtain 14000 RPM resulting in the range of Reynolds number up to 900. To characterize boundary layer we employ Laser Doppler Anemometry (LDA). We compare velocity profiles obtained in the laminar regime with the classical von Karman's approximation. According to [5] the onset of absolute instability occurs at $Re = 507$. In our case, laminar-turbulent transition occurs at $Re \approx 450$. The origin of this discrepancy might be ascribed to cross-flow instability triggered by surface roughness [3]. For higher Reynolds numbers, fully developed turbulent boundary layer is obtained.

In this work we address several aspects of droplet levitation:

- what is the droplet's shape influence on the lift force?
- does the turbulent boundary layer support a stable levitation?
- do droplets self-optimize their shape to maximize lift force?

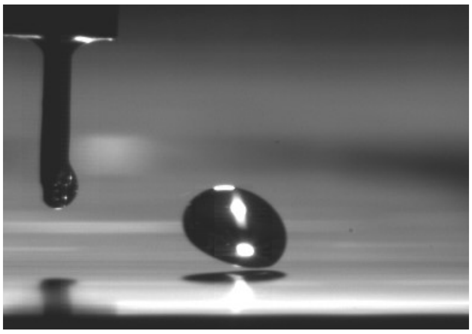

Figure 1: Droplet surfing on a laminar boundary layer

References

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