

Shear Driven Droplet Shedding on Surfaces with Various Wettabilities

Sara Moghtadernejad, Morteza Mohammadi, Mehdi Jadidi, Moussa Tembely, and Ali Dolatabadi
Concordia University Montreal

ABSTRACT

Experimental study is performed to analyze the shedding behavior of droplets with different shear flow speeds typical of those in the flight conditions. Droplet shedding phenomena has significant effect on ice accumulation on critical components such as airfoil and nacelle. In order to mimic this scenario experimental set up is designed to generate shear flow as high as 90m/s. The high shear effect is combined to the surface wettability impact by using hydrophilic and superhydrophobic surfaces. It is shown that the wetting length of the droplet on hydrophilic surface increases by shear speed while on the superhydrophobic surface a drastic reduction on wetting length is detected. Furthermore, it is observed that the droplet is detached from the superhydrophobic surface with moderate shear speeds.

CITATION: Moghtadernejad, S., Mohammadi, M., Jadidi, M., Tembely, M. et al., "Shear Driven Droplet Shedding on Surfaces with Various Wettabilities," *SAE Int. J. Aerosp.* 6(2):2013, doi:10.4271/2013-01-2176.

INTRODUCTION

Exposing shear flow to a sessile droplet which is placed on a substrate makes the droplet move. This movement is called shedding and only happens when the shear flow overcomes the droplet adhesion to the substrate. After the start of the droplet shedding, which is called the incipient motion, the droplet moves downstream along the surface [1]. Shear driven droplet shedding has various industrial applications such as in icing phenomena that occurs on airplane airfoils, wind turbine blades and power lines [2]. The knowledge can also be used in enhancing the performance of oil recovery systems [3]. In the following study, different air shear speeds ranging from 5m/s to 90m/s are used as the driving force to move the water droplet. Therefore, the outcome of the work can be more applicable for ice accumulations on airfoils, wind turbines and power lines. The reason is that in the mentioned applications, the droplets impact on the surfaces and later on start to move along the surfaces due to the air shear flow. Generally, on hydrophilic surfaces, the run back flow of the droplets results in the formation of narrow streams of liquid known as rivulets. Based on the surface morphology and shear driven forces rivulet can propagate on the surface and covers more area. When the ambient temperature is lower than the water freezing temperature, droplets and rivulets will be frozen and lead to significant damages on various components. For

example, in the case of airplane, ice accumulation significantly reduces the aerodynamics efficiency of the airplane by increasing drag and decreasing lift forces [4]. There are limited insights into fundamentals of air shear driven drop shedding in the literature especially on superhydrophobic surfaces. Although in the work of Milne and Amirfazli [1], droplet incipient motion due to lower shear flow speed (below 30m/s) was studied on different surface wettabilities, but the investigation at higher speed, close to those occur in aerospace applications is missing. In the following experimental study, different range of air shear speed is used on both hydrophilic and superhydrophobic surfaces. Study of the drop behavior on superhydrophobic surface is an active research area due to the high water repellency characteristics of these surfaces. As mentioned before, shedding occurs when the drag force overcomes the adhesion forces. It is known that both drag and adhesion depend on, contact angle of the surface (wettability), the size and shape of the droplet. Since the last two parameters are also a function of contact angle, the surface wettability is highly important in droplet shedding process [5]. As a result, except the shear flow and surface material, all other parameters like the droplet shape, size, temperature and humidity is kept constant in the experimental procedure.

EXPERIMENTAL PROCEDURE

The experimental setup enables recording the behavior of a sessile droplet while facing air shear flow. The shedding time is of the order of micro seconds; to capture the process precisely, a Photron SA1.1 high speed camera (Photron, California USA) operating at 10000frames/s with an UltraZoom 6000 lens (Navitar, New York USA) is used throughout the experiments. In order to illuminate the droplet shedding progression, an LED light (Schott, California USA) is used. In these experiments backlight method is used for capturing the images. To be able to see the droplet deformation completely, side view and top view images are taken from the shedding process. The air shear speed varies between 5m/s and 90m/s. Experiments are carried out on two rectangular plates with a size of 150×75×2 mm. The first plate is a polished aluminum which acts as a hydrophilic substrate with a contact angle of 75°. The second surface acts as a superhydrophobic with a contact angle of 155°, that surface is a polished aluminum plate coated with WX2100 spray (Cytonix, Maryland USA). A high pressure tank is applied to create the shear flow. Air is introduced on the substrate from the tank by using a tube with the inlet diameter of 10mm. The air velocity is controlled with a high pressure valve and the tube is attached to the substrate leading edge. Distilled water is deposited on the surface from a sterilized syringe at about 10mm away from the beginning of the substrate. The reason to choose 10mm away from the substrate leading edge, is that air stream is smooth and without any vortices at and after this location. The droplet diameter for each test is around 2.1mm which is subjected to the air flow at speed of approximately 7, 18, 34, and 90m/s. This is the air velocity that is measured with a pitot tube at the droplet position. It should be noted that each test is repeated ten times to reach an acceptable degree of accuracy. The reported results are the ensemble average of these ten experiments for each case. It should also be noted that all the experiments are performed at room temperature (about 22°C).

Table 1 shows the test matrix in addition to the surface characteristics. All the measurements in this work are post-processed with ImageJ software [6]. The details of the post processing methodology can be found in the work of Abramo *et al.* [6]. The experimental setup and schematic of the droplet shedding under the effect of air shear are shown in Figure 1.

Table 1. Test Matrix.

Surface Material	Aluminum	SHS
Contact Angle (deg.)	75±3	155±3
Contact Angle Hysteresis(deg.)	20±1	8±1
Shear Speed (m/sec)	7±1 18±1	34±2 90±5

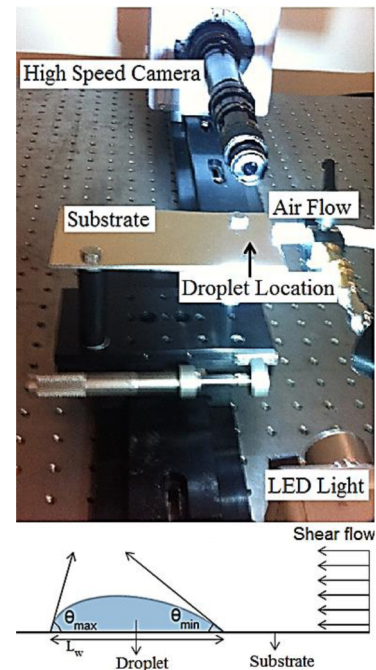


Figure 1. Experimental setup and schematic of the shear driven droplet shedding.

RESULTS AND DISCUSSIONS

Considering the droplet behavior during shedding, one of the interesting parameters to be measured is the wetting length of the droplet on the substrate. Wetting length (L_w) variation depends on substrate contact angle, droplet size and the air shear speed. Since in this study we have mainly focused on the effect of surface wettability and the air shear speed, the size of the droplets are kept constant in all the tests (about 2.1mm). To observe the effect of surface wettability and shear speed separately, one of these parameters is kept constant during one test and the other one is being changed. The top view and side view images that are recorded at different stages of the droplet movement are shown in Figures 2 and 3.

In the mentioned figures, the image sequences are associated to the lowest (7m/s) and highest (90m/s) air speeds. As can be seen in Figure 2 when the air velocity is low the droplet only oscillates on the substrate with a slow movement. However, for the case of high speed shear flow, the deformation of the droplet is in a way that a rivulet forms on the aluminum surface. In contrast, on superhydrophobic surface (SHS) in Figure 3, the droplet only rolls over the surface for low shear speed of 5m/s. For high shear flow (90m/s) the droplet deforms to an oval shape. After about 10ms the droplet detaches from the surface. As the droplet wetting length on SHS is less than hydrophilic surface due to the lower adhesion of the superhydrophobic material, the amount of ice accretion on superhydrophobic surfaces is less