Visualization Research of Droplet Deformation and Breakup in the Multimode Regime

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Abstract In this article, a visual study to investigate the breakup process and transient properties of the large droplets (d=700 μm) for different regimes was carried out. A new test rig was set up to explore the temporal evolutions of the breakups in an air nozzle. The control parameters, such as water droplets, liquid/gas density ratios of 815, Ohnesorge numbers less than 0.005 and Weber number ranges from 16 to 110 were considered. Experimental results showed that the bag breakup started at Weber number (We) of 16 and ends at We= 22, then followed the bag-stamen breakup. In bag-stamen breakup regime, volume of stamen, especially the liquid core at the top of the stamen increased with the increase of the Weber number, which involves the presence of the dual-bag breakup regime at Weber number of 30. Afterwards, the multi-bag breakup was approached when Weber number is 45 and ends with shear breakup in which bag structures are no longer present when Weber number reaches 80. In the present study, classic Rayleigh-Taylor instability (RTI) theory and internal flow theory are introduced to predict the wavenumber of R-T wave and analyze the breakup mechanism. The experimental results show good agreement with the theoretical analysis.
Keywords: Droplet breakup; jet flow, Weber number; droplet dynamics; transient

1 Introduction

In the condition of freezing rain, raindrops pass through sub-freezing layer hundreds of meters above the ground. Since the condensation nuclei are scare, those droplets are kept in liquid will coalesce into larger droplets despite the sub-zero temperature. Those larger liquid raindrops (d>500 μm) are normally studied as Supercooled large Droplets (SLDs), which exist in the extreme weather and could potentially endanger aviation safety. During the flight, the SLDs impact on the surface of the aircrafts and result in more serious consequences than the normal-size droplets. Since the deformation and fragmentation are neglected in the study of the normal-size droplets, which are usually assumed to be spherical and do not splash during the impact process. However, the surface tension and internal viscous force of SLDs are far less than the aerodynamic force, which means the large droplets deform and break up before they collide with the leading edge of the wings. And SLDs splash into smaller droplets after the collision and extend to unprotected zones of aircrafts, forming ice and increasing the risk of a subsequent aviation accident. Hence, aircraft icing occurring in the extreme weather conditions leads to serious consequences, which has attracted great attention of researchers in this research area.

2 Experimental Facility

The experimental study was conducted in the Anti-icing/de-icing research Laboratory at Beihang University, China. The whole system, shown schematically in Fig. 1, consists of five major components: mono-disperse droplet generator, water supply system, gas supply system, control system, and images acquisition system.

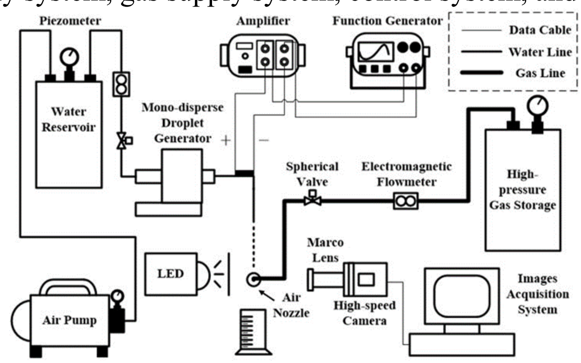

Fig. 1 Schematic of the experimental apparatus and instrumentation

3 Results and Discussion

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Table 1 Summary of experimental conditions

Item	Parameter	Range
1	Liquid water	Room temperature and atmospheric pressure
2	Initial drop diameter	700-720μm
3	Liquid/gas density ratio	815
4	Weber number	16-110
5	Reynolds number	1733-4545
6	Ohnesorge number	0.0043-0.0047

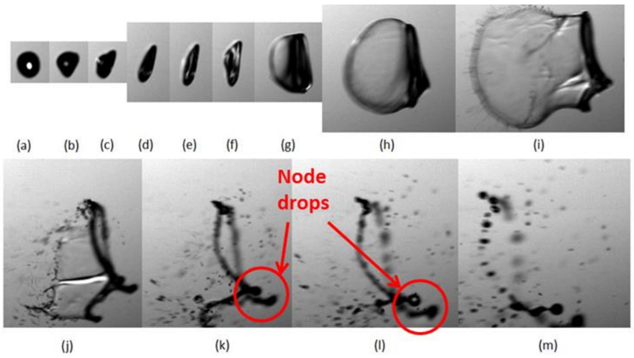

Fig.2 Experimental results in typical bag breakup regime (We=16). Air flow is from right to left. And the dimensionless time =a) 0, b) 0.449, c) 0.674, d)1.123, e)1.348, f)1.573, g)2.022, h)2.247, i)2.472, j)2.696, k)2.921, l)3.146, m)3.370

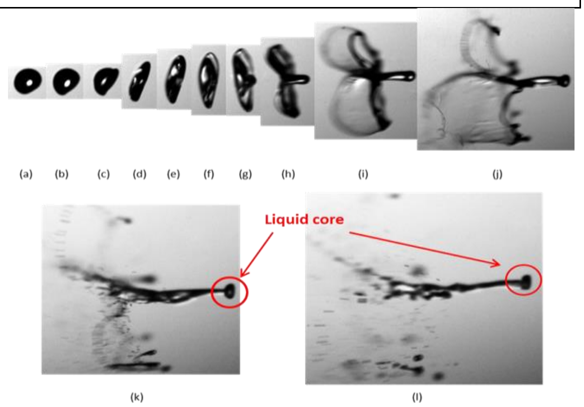

Fig. 3 Experimental results in typical bag-stamen breakup regime (We=22). Air flow is from right to left. And the dimensionless time t/t_c = =a) 0.259, b) 0.518, c) 0.777, d)1.296, e)1.555, f)1.814, g)2.073, h)2.247, i)2.332, j)2.591, k)2.850, l)3.109

Fig. 2 is an illustration of images of the droplet behavior in a typical bag breakup regime at We=16. The bag breakup can be defined as follows: Firstly, in the hemisphere period the windward of the droplet flattens and the leeward deforms little, therefore the initial spherical droplet will deform into a hemisphere at 0.449, where the characteristic timescale is , as shown in Fig.2a-b. Secondly, in the disc period the hemisphere deforms into a disc-like shape with uniform thickness at 1.348, as seen in Fig. 2c-e. Thirdly, in the bag formation period the center of the disc extends in the air flow direction, forming a membrane-like bag structure which gets thinner with time, and attaches to a much thicker toroidal rim surrounding it, as presented in Fig. 2f-h. Afterwards, in the bag breakup period the membrane starts to breakup in the rear end at 2.472 and deforms into thin ligaments which break up into a large number of tiny droplets owing to surface tension, as illustrated in Figs. 2i-k. Finally, in the rim breakup period the diameter of the toroidal rim fluctuates along the length direction and breaks up into a small number of larger droplets, as exhibited in Figs. 2l-m. Meanwhile, two node drops form on the equator of rim at 2.696 and disconnect from it as the rim breaks at 3.370, which are the largest child drops.

4 Conclusions

In this work, an experimental study was performed to investigate the different breakup regimes of a drop using a monodisperse droplet generator and continuous air jet. The major conclusions of the study are as follow:

(1) The breakup in bag-stamen breakup regime with increasing Weber number begins at the end of bag breakup (We= 22). In bag-stamen breakup regime, volume of stamen, especially the liquid core on the top of stamen increase with Weber number, which involves the presence of dual-bag breakup regime at We=30. Then

multi-bag breakup is approached at We=45 and ends with shear breakup in which bag structures are no longer present at We=80.

(2) In all "bag" breakup regimes, formation of the rims and node drops on it are observed and resulted from surface tension; and all of them serve as force-carrying structure and remain the stability of bag structure.

(3) In all multi-mode breakup regimes, liquid cores appear on the center part of the drop and increases with the Weber number: in bag-stamen breakup, it is on the top of stamen; in the dual breakup, it experiences bag breakup as a smaller drop; and in the multi-bag breakup, it is surrounded by several bag structures.

Acknowledgments

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