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Experiments on the Formation Process of Bag Breakup Regime of Injected Liquid Jet into an Airstream

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1. Introduction

The liquid jet, which is transversely injected into an air cross flow, has a board of range of applications in the air breathing engines such as diesel engines, gas turbine engines, and ramjet engines. The efficiency and stability of these engines depend on dispersion, atomization, and vaporization processes of injected liquid fuel jet. Hence, it is important to understand the fundamental physics and structures involved in the liquid jet injection because it helps to improve the performance of these engines.

When the liquid jet is injected vertically into a subsonic gaseous cross flow, the aerodynamic drag force causes the liquid jet column to be bend in the airstream direction, and also causes the acceleration waves generate and develop along the surface of the liquid column until the column of liquid jet breaks up into ligaments and droplets. This process is called liquid column breakup. The produced ligaments from the liquid column breakup undergo secondary breakup process and disintegrated to smaller droplets. By increasing the air Weber number, surface waves develop more on the liquid column and causes small droplets stripped from the leeward side of the liquid jet column before breakup point. This is called surface breakup.

As the air Weber number increases to around 5, the liquid jet column undergoes a particular deformation before breaking up into the ligaments and droplets. This is called bag breakup regime. In this regime, bag-like structures exist and develop on the liquid column. They expand until they become thin and the surface tension of the liquid jet is no longer enough to dominate the aerodynamic force. Eventually, they breakup into two crescent-shaped strings, and disintegrate to the small droplets.

In this study, we deal with the flow features of a liquid jet injected into an air stream in the bag breakup regime. Furthermore, the membrane and ring diameter size of the bags, which are formed on the column of jet, are obtained and compared.

2. Experimental Setup

The experimental setup used in this investigation was the conventional setup widely employed in the experiments of liquid injection. A liquid storage tank was pressurized by a compressed nitrogen capsule. The liquid tank was fed with tap water before performing tests and a baffle avoided undesirable interactions between high pressure gas and resting liquid. In the whole experiments, steady liquid flow was produced with a constant pressure difference of four bar between the ambient air and liquid tank. The liquid volumetric flow rate was controlled and measured via flow meters. Shadowgraph technique and a high speed camera were employed for the purpose of flow visualization. The schematic of the experimental setup is provided in Figure 1.

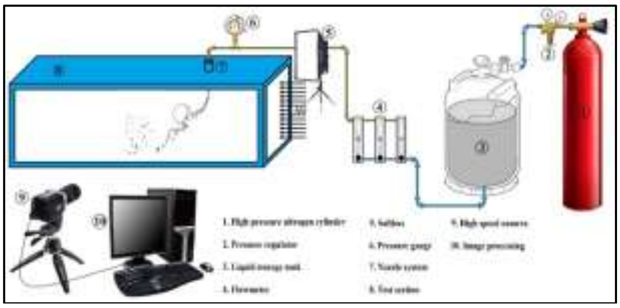

Figure 1. Schematic of the experimental setup

3. Image Processing Procedure

An image processing Matlab code was developed to identify the column of liquid jet, and extract data from the taken (original) images (Figure 2a). The image processing procedure is presented in Figure 2. Based on the difference of intensity between background and liquid jet edges pixels, a threshold was applied to detect the boundaries of the liquid jet column from the taken images (Figure 2b). After detecting the boundaries, the profile of the liquid jet column would be obtained as a binary image (Figure 2c).

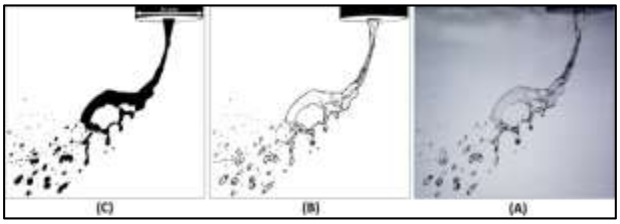

Figure 2. Image Processing: a) Taken Image, b) Boundaries, c) Profile of liquid jet

4. Results and Discussion

In this study, the size of membrane and ring diameter are calculated. Figure 3 shows the measured parameters on a bag, where λ denotes the membrane size and d_r indicates the ring diameter size of the bag.

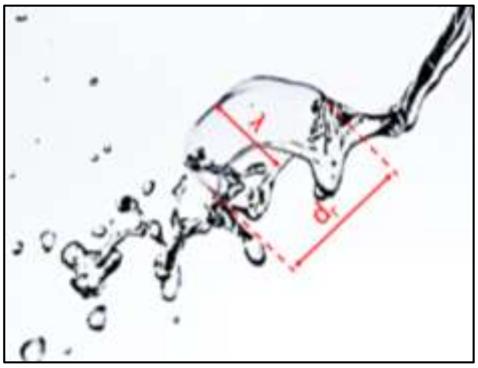

Figure 3. Measurements on a bag

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Figure 6. Bag breakup process

In this study, the size of membrane and the ring diameter of the bags were calculated and compared. The results, which are normalized by hydraulic exit diameter of nozzles, are presented in Figures 4 and 5. The performed calculations show that the dimensionless size of the membrane and the ring diameter is almost a constant value, and do not change by changing the liquid/air momentum ratio. It could be concluded that the size of bags (membrane and the ring diameter) is independent of air cross flow and liquid jet velocity.

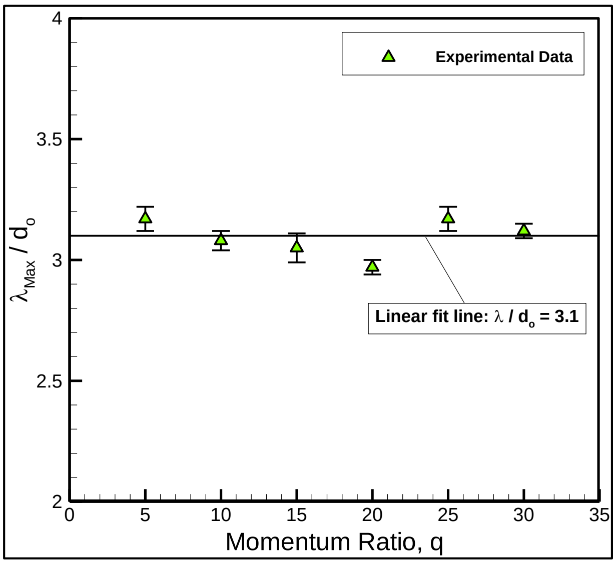

Figure 4. Membrane size (λ) of bags

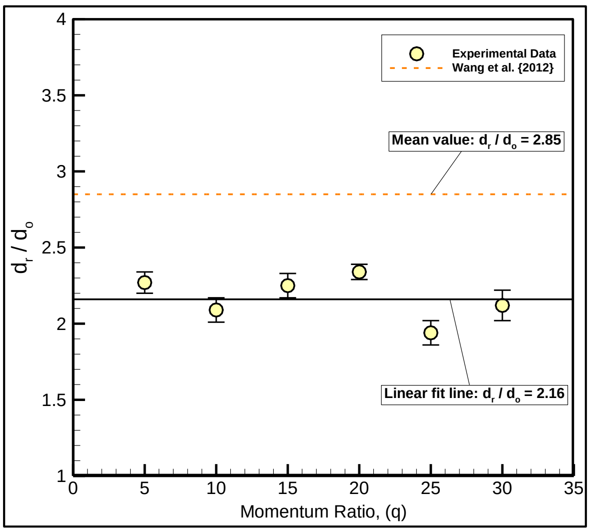

Figure 5. Ring diameter size (d_r) of bags

As mentioned earlier, after a bag exists and develops on the liquid column, it expands until it become thin and the surface tension of the liquid jet is no longer enough to dominate the aerodynamic force. Eventually, it breakup, and disintegrates into the small droplets. Figure 6 shows bag formation and breakup process.
Based on the obtained results, it is found that the membrane of a bag elongated in the stream wise direction of the cross flow, so membrane of the bag grew more than its ring. Figure 7 provides the comparison between the membrane and ring diameter of a bag in time.

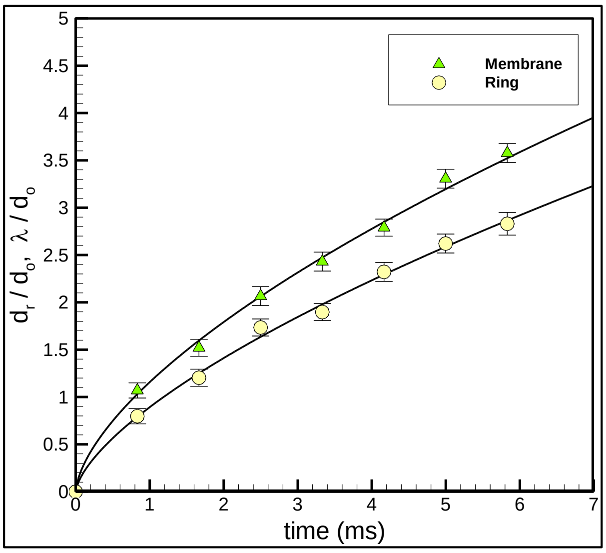

Figure 7. Variation of ring diameter and membrane size with time

5. Conclusion

In this study, the bag breakup process was experimentally investigated. Using shadowgraph technique and high speed photography, the jets flow was captured at different flow conditions. Different parameters such as size of ring and membrane of a formed bag were obtained. It was revealed that the normalized membrane and ring diameter of bags remain constant at different test conditions. The membrane and ring diameter size do not vary neither by changing momentum ratio nor air Weber number. It could be concluded that the size of bags (membrane and the ring diameter) is independent of air cross flow and liquid jet velocity. Finally, it was found that the membrane of a bag grows more than its ring towards the cross flow directions.