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Liquid-sheet Disintegration and Atomization by Multiple Jets Impingement under Effect of Impact Parameter

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Extended Abstract

In liquid rocket engines, jet impingement has a profound effect on atomization andmixing of the liquid-phase fuel and oxidizer and thus on the subsequent combustion performance. Practically, there existsa number ofmanners ofjet impingements, i.g.the like-doublet (O-O or F-F) impingement, unlike-double (O-F) impingement, multi-jet impingement, etc. As for the multi-jet impingement, noticeable at tention has been paid mainly on its influence to the mixing of fuel and oxidizer in terms of equivalence ratio. Atomization property arose under such impingement, however, still needs efforts to be understood.

The content of the present study is mainly on experimentally investigating atomization modes by multiple jets impingement under deferring impact parameter, *B*. Injector integrated with three water jets is employed herein to provide the impinging event. Fabrication of these injectors with different impact parameters are guaranteed by virtue of the intelligent manufacturing technology.

The aforementioned impact parameter,*B*,measures the deviation of impinging jets trajectory from the head-on situation and is defined as the ratio of spatially separation distance between the impinging jets to the value of jet diameter.According to the definition of *B*, it gives

$$B = \frac{2l \cdot \sin\theta}{d}$$

where l is the jet pre-impingement distance;θ is the angle of jet deflection; and$d$is the jet diameter.

In practice, when$B$=0, the three jets feature as head-on impingement; when $0<B<1$, the jets impingement skews; and when$B$=1, the grazing impingement where there is no mass transfer between the impinging jets.

Effects of impact parameter on liquid sheet disintegration and atomization under varying impinging Weber numbers (*We*s) is also considered in the present work. Four types of disintegration modesof the liquid sheet, under various *B*s,are observed and reasonably explained for the first time.

1. Symmetrical atomization

Generally, atomization by three jet impingement initiates by the formation of 'fishbone'-like structure, as illustrated in Fig.1, which composes of three lobes of fluid sheets extending laterally from a central

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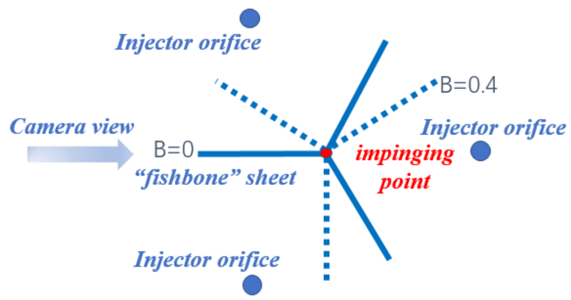
spine that starts at the impingement point. In the present experiment, the relative position between the high-speed camera and impinging jets takes the form as shown in Fig.1a. Under such camera light-path, two out of the three fishbone liquid sheets, from the front view of camera, can be in detailcaptured, as shown in Fig.1b, while the other one is exhibited merely as a liquid ligament which is actually the projective view of the third liquid sheet.

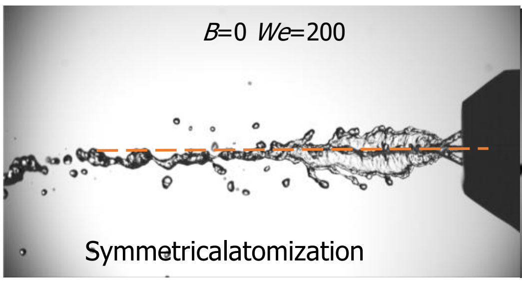
As to head-on impingement, the three liquid sheets are observed axially symmetric based on the phenomenon that two liquid sheets in the front view of camera are exhibiting in quite a similar shape, as shown in Fig.1b. Underlying reason of this phenomenon is that, during impinging process, the kinetic energy is at first transformed into the surface energy and this part of energy, then, rearranges to form the three lobes of liquid sheets in equal portion.In addition, it is also found in experiment that when continuously increasing *We*, the liquids sheets formed by the impinging jets are always subjected to a symmetric "fishbone structure" as comparing Fig.1b with Fig. 1d.

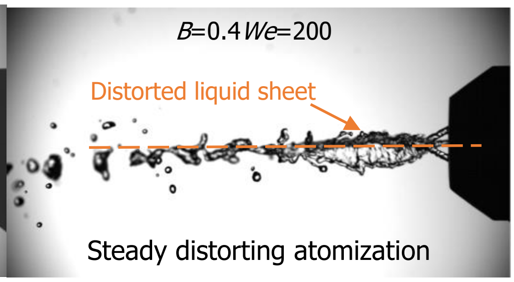
2. Steady distorting atomization

When *B* is moderately larger than 0, the three liquid sheets formed by impingement of the three skewed jets deflect to some extent as shown in Fig.1c where *B* =0.4 and *We* =200.Obviously, the two liquid sheets in the front view of camera become distinct such that the projective area of liquid sheet above the centerline of theinjector is much smaller than that of the liquid sheet below. This is because that, when *B* = 0.4, a portion of the collision kinetic energy has been used to distort the three liquid sheets instead of being restored as surface energy.

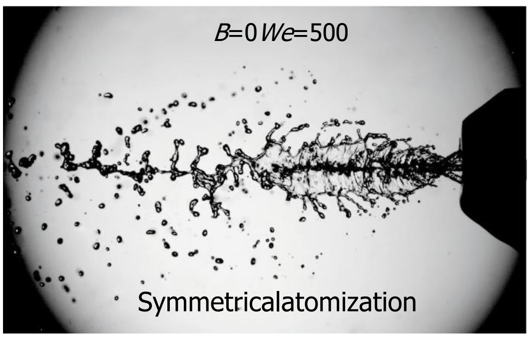


a





b c



d

Fig. 1. (a) schematic of impingement by three jets; (b) and (c), photographs of symmetrical atomization and steady distorting atomization; (d) The symmetric "fishbone structure" of symmetrical atomization at the larger *We*

3. Rotating atomization

When *B* remains 0.4, but at lager *We* of 1000, the atomization pattern turns to change periodically, as shown in Fig.2. In particular, from the shadow images, one can recognize that the upper and lower liquid sheets disappear in alternative. If the moment when the upper and lower liquid sheets are both existing is set as 0s, by counting the images captured at a speed of 5000 frames per second, we obtain the frequency of the alternative occurrence of 'single-lobe' liquid sheet is about 67Hz. It therefore indicates that the liquid sheet is rotating around the center of the injector at a certain speed.

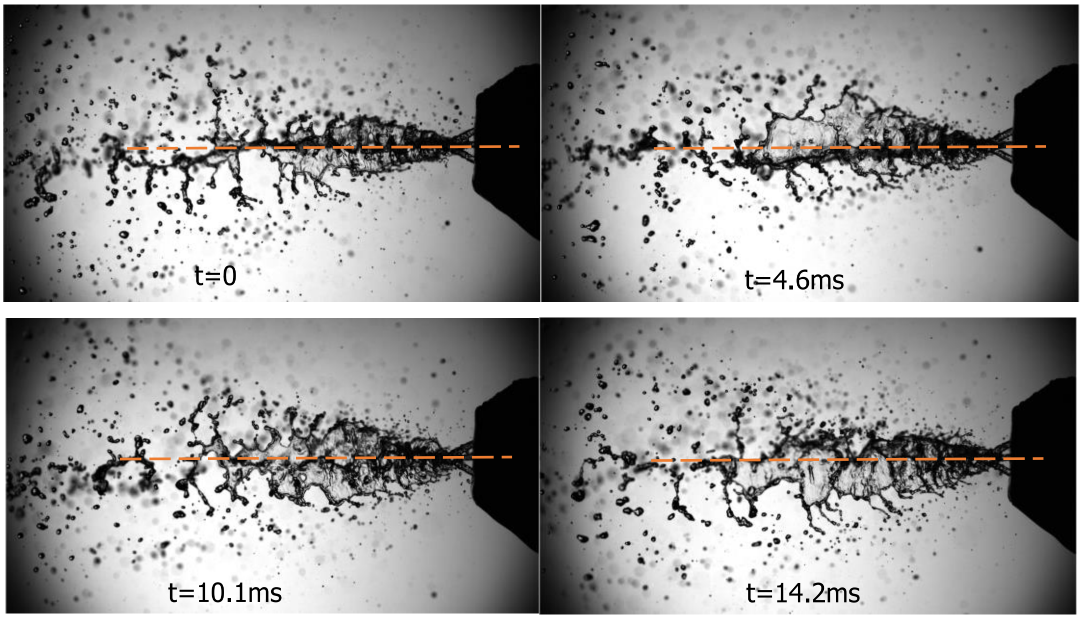


Fig. 2. Schematic of rotating atomization within one period of the changing of liquid sheets

In other to explain this phenomenon, we defined the rotating Weber number We_r as

$$We_r = \rho u_r^2 D/\sigma \ (1)$$

where u_r is the rotational speed, and its relationship with the impact parameter *B* is

$$u_r = \sqrt{We\sigma B/(2\rho l)}$$

where l is the length of the jet liquid ligament; ρ is the density of jet liquid; We is the impinging Weber number; and σ is surface tension.

It has been found that occurrence of rotation of the liquid sheet depends mainly on whether or not the inertial force that drive the rotation is sufficient to overcome the resistant surface tension from the liquid sheet.Therefore, there must exist a critical value of the rotating Weber number We_{rc1} so that whenWe_r is greater than the critical value the liquid sheets start to rotate,otherwise, the steady distorting atomization.

4. Stretching atomization

If *B* continuously increases to 0.8, a second critical rotating Weber number We_{r2} comes into effect. Under such situation, the liquid sheet tends to break immediately after impingement because of the strong shear force. From the experimental observation as shown in Fig. 3, it is noted that the liquid sheet has been stretched into ligaments, which will in turn disintegrate into small droplets.

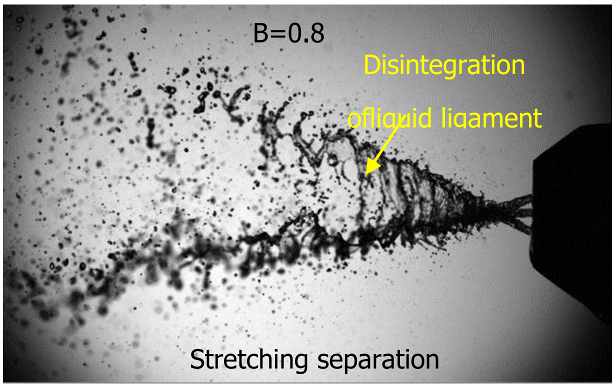


Fig. 3. Stretching disintegration of the liquid sheet under larger level of *B.*

Transition between the atomization modes defined above is substantially affected by the rotating Weber number, which is in turn influenced by the combination of impinging *We* and *B*. Note from Eq.(1) that when *We* becomes larger, smaller *B* will be needed to reach the first and second critical Weber numbers.That is, the larger the *We*, the easier it is to achieve the rotating atomization and stretching separation atomization modes.

Moreover, inference has been made herein that the distorting atomization mode and rotating atomization mode would affect the spatial distribution of the atomized droplets; while the stretching separation atomization mode may impose influence on the atomization angle and the atomizing droplets size (i.e. SMD), which all merits efforts in future work.