Flow Control of Impinging Atomization by Microjet

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Long Abstract

1. Introduction

In liquid rocket engines and satellite thrusters, several types of injectors have been proposed and used corresponding to combinations of propellants. Impinging jet injectors are preferred especially for engines that use storable propellants or liquid hydrocarbons as illustrated in Fig.1. Advantages of impinging atomization are its simplicity and good atomization characteristics at rated operations. The disadvantage is that operation range is restricted due to the deterioration of the atomization characteristics in off nominal operation with low injection velocities. In this study, to ensure good atomization and stable operation of engines under wide operation range, a small amount of fast gas (microjet) is implemented as a new and an active enhancement technique for impinging atomization[1]. The microjet is expected to assist like/unlike doublet type injectors only when the atomization characteristics deteriorate, and to stop at rated operation when good atomization can be realized without microjet. In the present study, experimental and also numerical investigations have been carried out to demonstrate the effect of microjet, to reveal the mechanism of the effect, and to optimize the microjet conditions.

2. Methods

In the case without microjet injection, the liquid (water) jets are injected into still air from two nozzles as shown in Fig.2(a). The diameter (D_L) is 1mm, the apex angle (2θ) is 40deg., and the impact point is 22.5mm from the nozzle exit. In the case with microjet injection, the microjet is injected toward the impingement point as shown in Fig.2(b). The microjet nozzle diameter (D_G) is 0.5mm. The exit of the microjet nozzle is set 5mm above the impingement point. The area downstream of the microjet nozzle exit is expected to be inside the combustion chamber. The atomization process was visualized by a high-speed video camera. When droplet diameters and velocities were measured, a double pulse YAG laser was used, and the images of droplets were taken by a CCD camera.
Eulerian-Lagrangian hybrid method has been developed to clarify the detailed flow field. In a computational grid system, Eulerian analysis was carried out based on the coupled scheme[2] of PLIC-VOF and Level-Set method. Dispersed drops are converted to particles, and are tracked in Lagrangian form.

3. Effects of Microjet Injection

Figure 3 shows visualization results in the case with and without microjet injection. In the case without microjet, atomization occurs through jet collision, liquid film formation, elongation and breakup of ligaments. By the microjet injection with mass flow ratio of only 1.0% to the liquid jets, the liquid sheet due to jet collision is no longer recognized. Around the impingement point, droplets are instantaneously produced, and atomization is significantly enhanced. SMD is one-tenth of the original case without microjet. The numerical results shows that the continuous sheet suddenly breaks up by the microjet, which corresponds to the experimental results.

A criteria for an effective condition of microjet is investigated. The microjet enhances atomization when the total pressure of the microjet overcomes that of the liquid jet at the collision point. This condition can be presented by the following equation:

$$p_a + \frac{1}{2}\rho_G V_{imp.}^2 \geq p_a + 2\frac{\sigma}{D_L} + \frac{1}{2}\rho_L V_L^2 \,. \qquad (1)$$

Here, p_a, ρ_G, ρ_L, V_{imp}, V_L and σ mean ambient pressure, microjet density, liquid density, microjet velocity at impingement point, liquid velocity, and surface tension coefficient, respectively. Then, the threshold is obtained regarding the ratio of dynamic pressure (microjet/liquid) at the impingement point q_{imp} as:

$$q_{imp.} \equiv \frac{\rho_G V_{imp.}^2 / 2}{\rho_L V_L^2 / 2} \geq 1 + \frac{4}{We_L} \sim 1 \,. \qquad (2)$$

As the results of optimization, it is recommended to set the microjet injection condition as $q_{imp.}$~2.

4. Conclusions

To enhance and control impinging atomization at off design operations, an active technique, which utilized microjet injection, was proposed. Both of the experimental and the numerical investigations verified the effects of microjet, and revealed the mechanism of the atomization enhancement. It was demonstrated that a fast microjet was able to remarkably enhance atomization with only 1% of the mass flow rate of the liquid jets, e.g. SMD became one-tenth of the original value. Dominant non-dimensional number was found to be the ratio of dynamic pressure (microjet/liquid jet) at the impingement point. When the dynamic pressure ratio was larger than approximately 1, impinging atomization was drastically promoted.

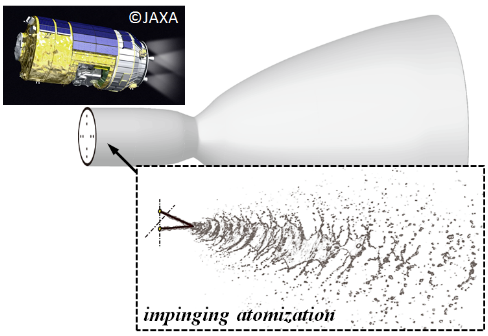
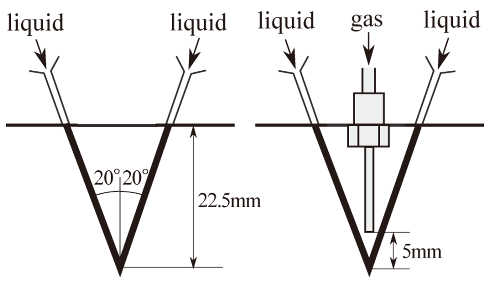
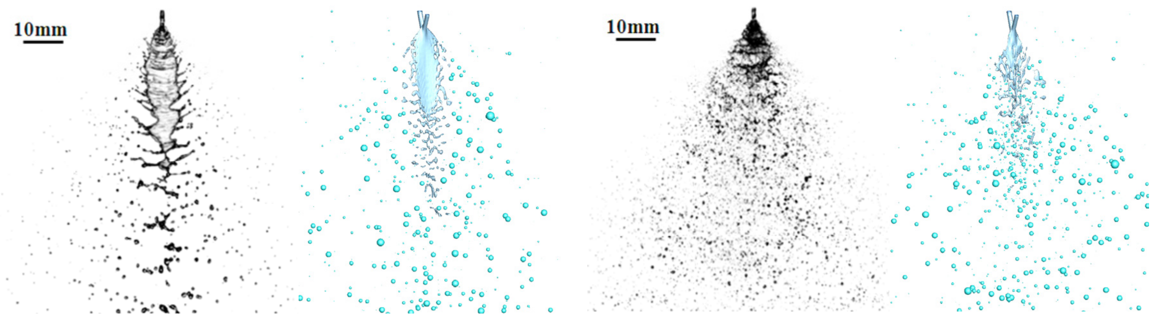


Fig.1 Impinging atomization in thrusters



(a)w/o microjet (D_L=1.0mm) (b)with microjet (D_L=1.0mm, D_G=0.5mm)

Fig.2 Nozzle schematic



(a) w/o microjet (left: exp, right: CFD) (b) with microjet (left: exp, right: CFD)

Fig.3 Effect of microjet injection on impinging atomization

References

[1] Inoue,C., Watanabe,T., Himeno,T. and Uzawa,S., "Impinging Atomization Enhanced by Microjet Injection - effect, mechanism and optimization -", AIAA2013-3705.

[2] Himeno,T., Watanabe,T., and Konno,A., "Numerical Analysis for Propellant Management in Rocket Tanks," Journal of Propulsion and Power, Vol.21, No.1, 2005.