Experimental Study on the Pulsation of a Liquid Jet Issued from a Coaxial Injector

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Abstract

The mechanism of the onset of pulsation of liquid jet issued from a coaxial injector was experimentally studied. A two-dimensional transparent injector element model was used to observe the pulsation of the liquid jet in a recess region. In order to prevent a liquid injection post from pulsation, which may cause the liquid jet pulsation, the injector with only one-side gas flow channel was used. Pressure variation in a recess region and the sound caused by the liquid jet disintegration were also analyzed in order to clarify the condition for the transition of jet disintegration pattern. At a certain liquid Reynolds number and gas Weber number, the liquid jet at the exit of the post expanded and, finally, reached the outer edge of the post. This expansion behavior of liquid jet enhances the contact of liquid and fast gas flow, and thus atomization. The critical gas Weber number and liquid Reynolds number over which the liquid jet expands observed in the case of only one-side gas channel corresponds to the critical numbers for the flow transition of a jet issued from a liquid injection post with tow-side gas channel.

Introduction

Coaxial injectors are widely used in a rocket engine. Liquid oxigen jet issued form a central injection post of the injector is atomized by a high-speed hydrogen gas flowing around the liquid oxigen jet. The breakup patterns of the liquid jet were classified by Chiger et al.[1] by using liquid Reynolds number and gas Weber number. Nunome et al.[2] clarified the critical Reynolds number and Weber number, over which the jet disintegration mode changes from pulsation to super-pulsation disintegration, for a coaxial injector with recess. In that previous study, they used a two dimensional injector model with two-side gas flow channel, which allowed the pulsation of liquid injection post, and observed the pulsation of both liquid jet and injection post. The mechanism for the onset of the pulsation is not fully understood. In the present study, therefore, in order to prevent the injection post from pulsation, an injector model with only one-side gas flow channel is used.

Materials and Methods

Figure 1 shows the schematic diagram of the injector model. The liquid injection post has a cross sectional area of 4.0 $\times$4.0 mm^2 with 0.3 mm thickness while the width of gas channel is 2.0 mm. Recess depth was varied by inserting a spacer. Recess pressure was measured through pressure port 1, 2 and 3. The disintegration pattern of the liquid jet was observed with a high-speed camera (Shimadzu, HPV-1: framing rate 63000 fps) or a still camera. The sound caused by the liquid jet disintegration was also measured at the sampling rate of 44.1 kHz using a microphone. The sound data were analyzed with spectrogram method, in which the time variation of power spectrum is obtained.

Flow tests were conducted by using water and nitrogen gas under the ambient pressure of 0.1, 0.2, 0.3, and 0.4 MPa. The liquid Reynolds number (Re_L) and the gas Weber number (We_G) were varied in the range of 2000 to 4000 and 3000 to 10000 respectively.

$$Re_L = \frac{U_L d_L}{\nu} \tag{1}$$

$$We_G = \frac{\rho_G (U_G - U_L)^2 d_L}{\sigma} \tag{2}$$

Results and Discussion

Figure 2 shows a typical experimental result of time variation of recess pressure and liquid flow rate. In this experiment, the gas velocity was kept constant at about 150 m/s while the liquid flow rate was gradually decreased. A remarkable step-wise change in recess pressure is found in figure 2 at t = 0. The corresponding spectrogram image for frequency range between 100 and 3000 Hz is shown in figure 3. A step-wise change in power spectrum at t = 0 in the ragne between 100 and 1000 Hz which corresponds to the sound of liquid jet pulsation is also found in this figure. The photographs of liquid jet shown in figure 4 reveals that the pulsation

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amplitude of the jet drastically increases after t = 0. We thus determined Re_L and We_G at t = 0 as critical Reynolds and Weber numbers for flow regime transition. When the gas velocity is further increased, this step-wize change in recess pressure and spectrogram disappeares, and only gradual change was obtained. The flow regime transition was thus determined from photographs following the fact that after the transition the radius of liquid jet at the exit of the post expands to the outer edged of the post.

The critical Re_L and We_G for recess depth of 1.5 d_L are plotted in figure 5. For comparison, the non-dimensional parameters obtained by Nunome et al.[2] using an injector model which allows the pulsation of the liquid injection post is also shown in this figure. It is clearly shown that the critical Re_L and We_G obatined in the present study corresponds to that in the previously obtained ones. This indicates that the expansion and the following pulsation of liquid jet triggers the pulsation of a liquid injection post.

Nomenclature

U_L	velocity of liquid [m·s^{-1}]	σ	surface tension coefficient of liquid [N·s^{-1}]
U_G	velocity of gas [m·s^{-1}]	ρ	density of liquid[kg·m^{-3}]
d_L	width of liquid post [m]	ν	kinematic viscosity of liquid [m^2·s^{-1}]

References

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[2] Nunome, Y., Tamura, H., Onodera, T., Sakamoto, H., Kumakawa, A., Inamura, T., *45th AIAA / ASME / SAE / ASEE Joint Propulsion Conference & Exhibit*, Denver, CO, August 2009, No. AIAA-2009-5389(DVD).

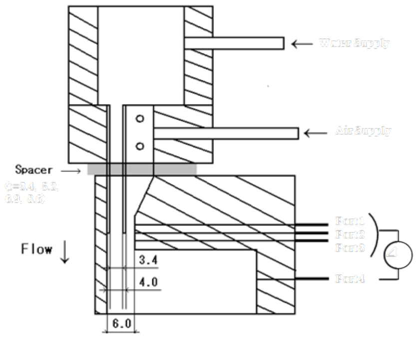


Figure 1. Schematic diagram of the injector model.

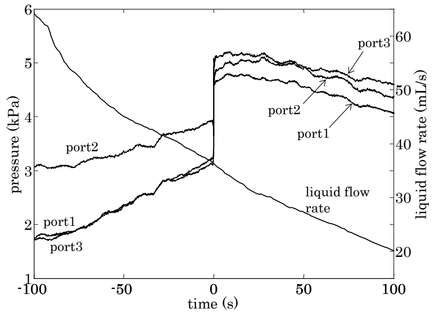


Figure 2. Time variation of recess pressure and liquid flow rate

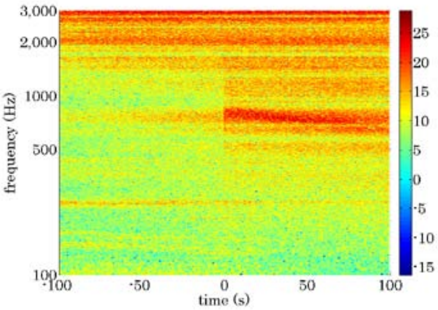


Figure 3. Spectrogram of the sound caused by liquid jet disintegration.

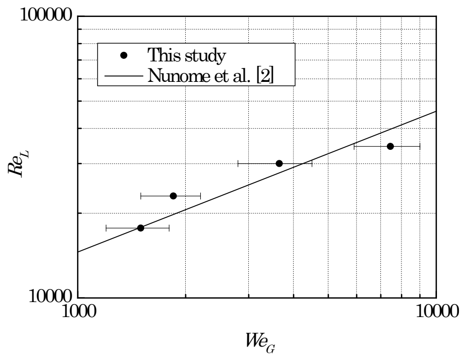
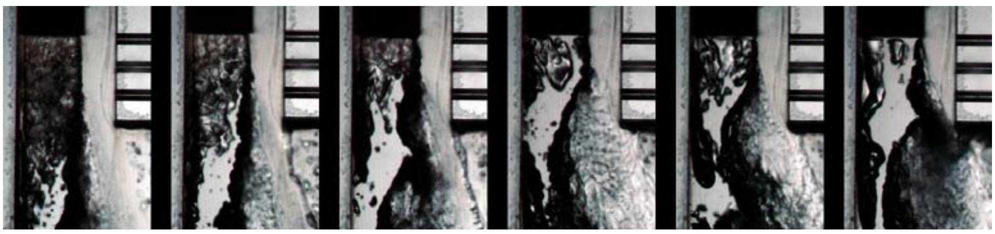


Figure 5. Critical Reynolds and Weber number for the transition of disintegration regime.



-173.5 s -95.0 s -6.85 s 0.65 s 2.4 s 18.65 s

Figure 4. Photographs of liquid jet issued from a liquid injection post.