LDV MEASUREMENT OF CAVITATING FLOWS IN A TWO-DIMENSIONAL NOZZLE

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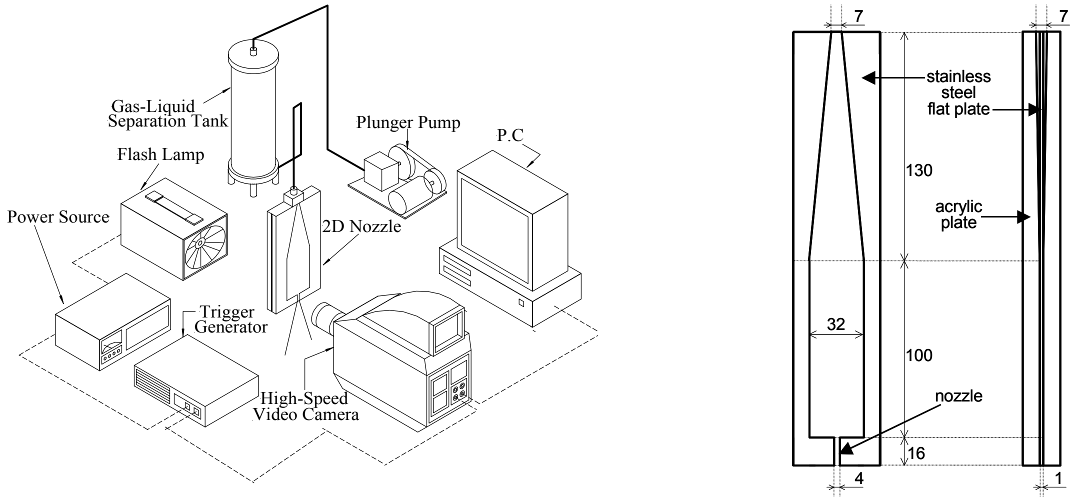
INTRODUCTION

It has been pointed out through a lot of experimental studies that cavitation takes place in a fuel injector nozzle of a Diesel engine and the cavitation and the internal flow in the nozzle greatly affect the atomization of the discharged liquid jet. Hiroyasu et al. [1] showed that liquid jet atomization was promoted when cavitation extended from the nozzle inlet to its exit. Nozzle shapes used in most of the previous experiments have been cylindrical, and thereby, it has been difficult to clearly capture the configuration of cavitation bubbles. Henry and Collicott [2], on the other hand, obtained clear images of cavitation bubbles by using two-dimensional (2D) nozzles. As for the velocity distribution in a nozzle, only a few studies have been conducted. Walther et al. [3] measured a velocity field in a sac hole using Fluorescent Particle Image Velocimetry. However, the internal flow in the nozzle was not accurately measured. Gnirss et al. [4] succeeded in measuring a streamwise velocity profile at the exit of a 2D nozzle. The present authors [5] recently visualized transient cavitation phenomena in a 2D nozzle using an ultra high-speed video camera system, whose exposure time is short enough (5 nsec) to obtain frozen images of cavitation bubbles. In the present study, liquid velocity distributions in the same 2D nozzle were measured using a Laser Doppler Velocimetry (LDV) system to investigate the effects of cavitation on the internal flow and its turbulence.

EXPERIMENTAL SETUP

The schematic of an experimental setup is shown in **Fig.1(a)**. Tap water was injected into ambient air from the 2D nozzle of 4 mm in width W_N, 16 mm in length L_N and 1 mm in thickness as shown in Fig.1(b) and (c). The lateral velocity u and the streamwise velocity v of water were measured using an LDV system. Experiments were carried out under various conditions. The Reynolds number Re ($=V_N W_N/\nu_L$) and the cavitation number $\sigma = (P_a - P_v)/(0.5\rho_L V_N^2)$ were used as dimensionless parameters. Typical experimental conditions are listed in **Table 1**.



(a) Experimental setup (b) Front view of 2D nozzle (c) Side view

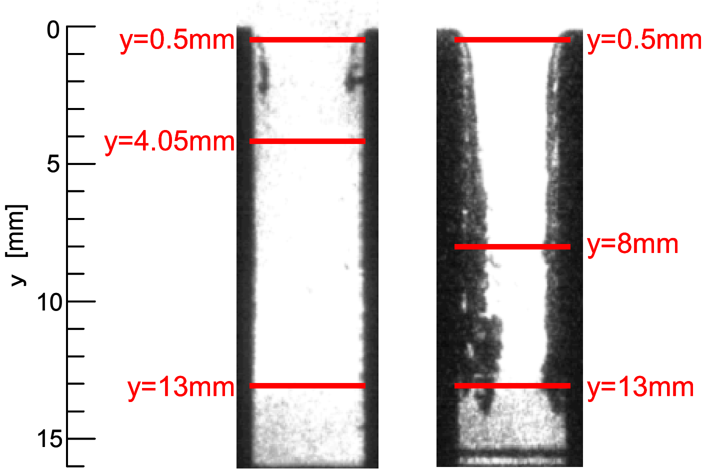
Fig. 1 Experimental Setup and 2D Nozzle

RESULTS AND DISCUSSIONS

Images of cavitation in the 2D nozzle are shown in **Fig.2**. When $\sigma \geq 0.78$, clouds of cavitation bubbles were observed as shown in Fig.2(a) (developing cavitation), and the liquid jet took a wavy jet form. When $\sigma \leq 0.69$, a large smooth cavitation extended across the nozzle, and clouds of cavitation were observed in the lower half of the nozzle as shown in Fig.2(b) (super cavitation). The liquid jet took a spray form with ligaments and droplets.

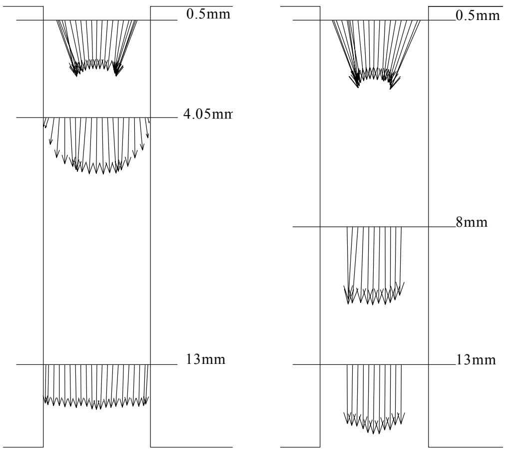
Mean liquid velocities in the 2D nozzle are shown in **Fig.3**. In the developing cavitation regime, the reattachment of a Separated Boundary Layer (SBL) occurred in the middle of the nozzle as shown in Fig.3(a). Velocity fluctuation increased just below the cavitation zone. However, it decreased in the downstream region above the exit. This could be the reason of the wavy jet regime. In the super cavitation regime, the streamwise velocity, V, in the core region increased as shown in Fig.3(b).

Figure 4 shows the velocity fluctuation, v', at $\sigma = 0.65$. Velocity fluctuation in the core region increased with y, which might be caused by the instability of the interface of a large cavitation bubble and/or the dynamic instability of the shear layer. These instabilities might be tightly related with the formation of the spray regime and the drastic promotion of the liquid jet atomization.



(a) σ=0.94, *Re*=58000 (b) σ=0.65 *Re*=70000

Fig.2 Images of cavitation in the 2D nozzle



(a) σ=0.94, *Re*=58000 (b) σ=0.65 *Re*=70000

Fig.3 Mean velocity in the 2D nozzle

Table 1 Typical experimental conditions

Averaged liquid velocity, V_N [m/s]	Reynolds number, $Re = \dfrac{V_N W_N}{\nu_L}$	Cavitation number, $\sigma = \dfrac{P_a - P_v}{0.5\rho_L V_N^2}$
11.25	45000	1.57
12.5	50000	1.27
14.5	58000	0.94
16.0	64000	0.78
17.0	68000	0.69
17.5	70000	0.65

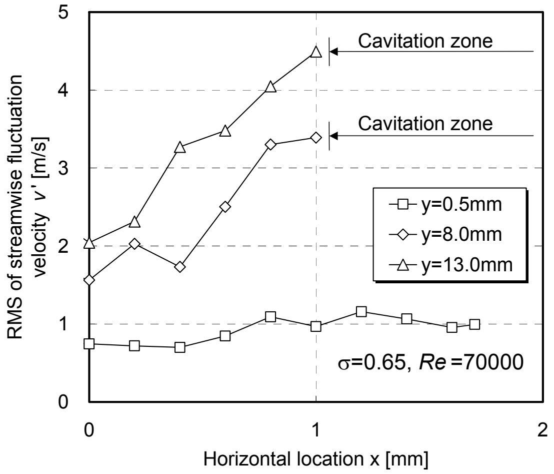


Fig.4 RMS of velocity fluctuation v' at σ=0.65 and *Re*=70000

CONCLUSION

Liquid velocity distributions in cavitating flows in a two-dimensional (2D) transparent nozzle, for which ultra high-speed video images of cavitation had been taken, were measured using a Laser Doppler Velocimetry (LDV) system. As a result, the following conclusions were obtained:

(1) A mean flow flowing through the sharp-edged inlet corner of the nozzle was a sort of a pseudo-potential flow with a separated boundary layer (SBL), and the inception of cavitation took place at the outer edge of SBL, where the local velocity took the highest value and the pressure was lower than the vapor saturation pressure.

(2) The presence of a recirculation flow in SBL was confirmed by the measured liquid velocity distribution.

(3) When the cavitation number σ was greater than 0.78, the reattachment of SBL occurred in the middle of the nozzle, and no cavitation bubbles were observed in the downstream region. Turbulent intensity increased just below the cavitation zone. However, due to the large turbulent mixing the turbulence intensity near the exit of the nozzle decreased, which resulted in the formation of a wavy jet without ligaments and droplets.

(4) When σ was less than 0.69, the mean streamwise velocity and the turbulent intensity in the core region increased with y, which might be caused by the instability of the interface of a large smooth vapor bubble and/or the fluid dynamic instability of the shear layer. They might cause a drastic promotion of liquid jet atomization.

ACKNOWLEDGEMENT

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