Reconstructed 3D flame structures in noise-controlled swirl-stabilized combustor

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ABSTRACT

Lean premixed combustion with high inlet temperature is considered to be a strong candidate for high efficiency and low emission gas turbines. However, the lean premixed combustion may induce combustion oscillations or instabilities. The reductions of the combustion noise and oscillation will lead to the development of high-efficiency low-emission combustors. Combustion control by secondary fuel injection has been studied by Samaniego et al. (1995) and Broda et al. (1998). In our previous study (Choi et al. 2005), local flame structure and its relation to combustion noise has been investigated by using simultaneous OH and CH planar laser induced fluorescence (PLIF). Due to the modification of local flame structure by the secondary fuel injection, combustion noise and NO_x emission can be reduced. Furthermore, by controlling injection frequency, combustion noise is minimized (Tanahashi et al. 2004). To realize an effective and robust active control of combustion, a detailed understanding of the combustion oscillation and instability mechanism is necessary. In this study, flame structures of turbulent premixed flames in a noise-controlled, swirl-stabilized combustor are investigated by PLIF to clarify the mechanism of combustion noise reduction by the secondary fuel injection.

In the re-circulation zone and the flame zone, PLIF is conducted for several cases with different secondary fuel injection. The flow rate of the main methane-air mixture (Q_m) is selected to 300*l*/min (equivalence ratio $\phi = 0.717$) and that of the secondary fuel injection (Q_{sf}) is set to 1% of Q_m to all cases (total equivalence ratio $\phi = 0.819$). As a reference, no control case with $\phi = 0.717$ is selected. Frequencies of the secondary fuel injection are changed as continuous, 10Hz, 40Hz and 70Hz.

Comparisons with the no control case show that fluctuation of high-temperature gas in the re-circulation zone is suppressed by secondary fuel injection and is slightly affected by the frequency of the secondary fuel injection. These results suggest that the secondary fuel injection works for control of the Reynolds stress term and entropy term due to the turbulent energy dissipation in the acoustic sound source. In the flame zone, effects of the injection frequency become clear by introducing probability of the flame existence. As for the no control case, very wide flame brush, which means the large fluctuation of the entropy term in the sound source, are created in the flame zone. However, the flame brush becomes thin and is confined to a narrow space for the secondary fuel injection cases. The investigated combustor gives minimum sound level at a relevant fuel injection frequency (in this case 40Hz) which is very low compared with the natural acoustic mode of the combustor. At the relevant frequency, the flame brush becomes thinnest. This suppression corresponds to the reduction of spatial and temporal fluctuation of the sound source.

To investigate effects of frequency of the secondary fuel injection, 3D flame structures are reconstructed from OH PLIF measurement obtained on multiple planes as shown in Fig. 1. For the no control case, contour surfaces of three probabilities show different shapes, which means that fluctuations of the high-temperature fluid in the re-circulation zone and the flame front in the flame zone are high. Compared with the no control case, the flame zone spreads into the outside for secondary fuel injection cases. The regions with the flame front are pushed up by the jets of the secondary fuel, and no-flame regions intrude into the downstream. The flame brush for the 40Hz injection case is more localized compared with the continuous injection case. For the 40Hz injection case, the shape of the flame brush is independent of the injection phase compared with the different frequency cases and the spatial and temporal fluctuation of flame front is suppressed. The reconstructed 3D flame structure shows that flame front dynamics are well controlled by the secondary fuel injection.

(a)
(b)
(c)

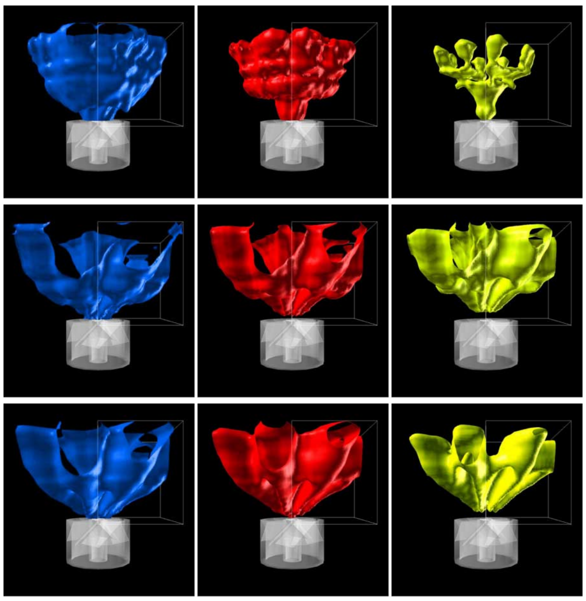

Fig. 1 Three-dimensional distribution of probability of flame front existence (30% in unburnt side, 50% and 30% in burnt side from the left) for the no control case (a), continuous secondary fuel injection case (b) and intermittent secondary fuel injection case at 40Hz (c).