Simultaneous dual-plane CH PLIF/single-plane OH PLIF and dual-plane stereoscopic PIV in turbulent premixed flames

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Simultaneous dual-plane CH planar laser induced fluorescence (PLIF), single-plane OH PLIF and dual-plane stereoscopic particle image velocimetry (PIV) measurement has been developed to investigate three-dimensional structures of methane-air turbulent premixed flame.

Figure 1 shows the schematic of simultaneous measurement system. Dual-plane CH PLIF system consists of two independent conventional CH PLIF measurement systems (XeCl Excimer/Dye and Nd:YAG/Dye lasers). Laser beams from each laser system are led to parallel optical pass by using the difference of polarization. Dual-plane stereoscopic PIV using nonspherical particles can be accomplished by utilizing the difference of laser wavelength. One plane is illuminated by 532 nm laser and another is done by 560 nm one, which is established by two Nd:YAG lasers and two dye lasers. The dual-plane measurements of CH PLIF and stereoscopic PIV are conducted in the same two-dimensional cross sections. The dual-plane CH PLIF and stereoscopic PIV are combined with single-plane OH PLIF. The laser sheet for single-plane OH PLIF is located at the center of two planes for CH PLIF and stereoscopic PIV. The separation between each plane is set to about 170 μm. The spatial resolution of velocity in the dual-plane stereoscopic PIV is 175μm (about three times Kolmogorov length scale) × 175μm × 210μm, and is same as that of general direct numerical simulations (DNSs) of turbulence. The spatial resolutions of CH PLIF and OH PLIF are 29.1μm × 29.1μm × 210μm, 56.6μm × 56.6μm × 242μm, respectively. This simultaneous measurement can provide three-dimensional flame front, three velocity components and nine velocity derivatives. The simultaneous measurement is conducted in methane-air swirl-stabilized turbulent premixed flames of Re = 63.1, 95.0 and 115.0.

Figure 2 shows typical three-dimensional flame structures of methane-air turbulent premixed flame for Re = 63.1 and 95.0. The visualized domain is 23.6 mm × 23.6mm × 340μm. The isolines drawn by dark gray and white represent fluorescence intensity distributions of CH radicals on each plane, and the gray area represents the unburnt mixture obtained by fluorescence intensity distribution of OH radical on the central plane. The visualized distance between two measured planes is set to be about fifteen times the real scale for easy understanding. White line represents the integral length scale (l) of turbulence for each case. Flame structures are heavily fluctuating, and have small-scale wrinkling less than Taylor micro scale. The region A in the realization shown in Fig. 2 (a) represents a separating flame structure. Large mass of unburnt mixture exists on the back and central planes, whereas flame is divided into almost three parts on the front plane represented by I, II and III. In Fig. 2 (b), flame surface is folded and thin layer of unburnt mixture is created as shown by the region B. Furthermore, thinner layers of unburnt mixture are generated in the higher Reynolds number condition (see the full-manuscript). The information on three-dimensionality of local flame structure allows us to evaluate two principal curvature of three- dimensional flame surface.

In the full-manuscript, the strain rate which is obtained from nine velocity gradients is represented and discussed with the three-dimensional flame structure. As a result, the advantage of the simultaneous dual-plane CH PLIF, single-plane OH PLIF and dual-plane stereoscopic PIV measurement is shown in the full-manuscript.