Unsteady Stretch Interaction between Premixed CH_4/Air Flame and Decaying Turbulent Wake

S. S. Shy*, C. C. Lee, S. I. Yang, R. C. Su and W. H. Lee

Department of Mechanical Engineering
National Central University
Chung-Li 32054, Taiwan

*Corresponding author:

Prof. S. S. Shy

Department of Mechanical Engineering, National Central University, Chung-Li 32054, Taiwan

E-mail: sshy@cc.ncu.edu.tw; Fax: 886-3-425-4501

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Abstract

This note describes experimentally the interaction between a downwardly propagating rich premixed CH_4/air flame and a decaying turbulent wake in a 1.5 m long vertical burner with a cross-sectional area of 15×15 cm^2 (see Fig. 1). Before a run, the burner was evacuated and then filled with methane-air mixtures at a given equivalence ratio at 1 atm. A run began by ignition at the top of the burner where the whole top plate was simultaneously opened in order to generate a downwardly propagating premixed flame at 1 atm. When the downwardly propagating flame was approaching near a horizontal plate of 0.50 cm thickness that was initially positioned at 1.0 m below the top of the burner, the electrically-controlled horizontal plate was quickly withdrawn to create a turbulent wake for flame-wake interactions. Figure 1

displays such an experimental arrangement.

Also plotted is a typical unreacting turbulent wake that is generated by sliding the horizontal plate, as can be seen on the upper right of Fig. 1, where the laser tomography with seeding oils only one side above the sliding plate is applied to obtain the planar image of the turbulent wake. The present wake develops into a parallel row of staggered vortex pairs, similar to the Kármán vortex sheet behind a circular cylinder. On the lower right of Fig. 1, a typical instantaneous unreacting flow velocity map of the above turbulent wake at the same time moment after sliding the plate is presented using the digital particle image velocimetry (DPIV). Note that the wanted flame-wake interaction and its velocity field are obtained using high-speed laser tomography and DPIV. Hence, the corresponding strain rate, curvature, and dilatation rate along the flame front at different times can be determined.

Figure 2 shows two original DPIV images of a downwardly propagating rich premixed CH_4/air flame (the equivalence ratio ? = 1.45 for lower laminar flame speed) interacting with the above turbulent wake at t = 110 ms and 140 ms after sliding the plate, respectively. These corresponding instantaneous reacting flow velocity and vorticity maps of the flame-wake interaction are displayed on the lower part of Fig. 2, where the stretched flame fronts are superimposed. As can be seen from Fig. 2, when the tip of the vortex pair is pointing toward/away from the downwardly propagating flame, the corresponding vortex pair experiences an extensive/compressive strain. It is observed that flame-wake interactions are much more intense in vortices whose strain are compressive than those with extensive strain. This is because the compressive vortex pair can engulf the flame deeply into its clockwise-rotating vortex core. Combustion starts from the core with a burning rate much faster than the other half (counterclockwise-rotating) vortex that is also a half of the extensive strain vortex pair. We found that the curvature on the wrinkled flame front has a much stronger influence on the stretch rate than the strain rate does in the present flame-wake interactions. Furthermore, dilatation rates reveal peak values very near the flame front, so that the local peak dilatation rate may be used as an indicator of the local flame strength, in support of the work done by Driscoll and his co-workers [1] for a single axisymmetric vortex pair interacting with a premixed flame. The flame strength increases when the negative strain is applied to the compressive vortex pair, while the flame strength has no significant increase as the positive strain is applied to the extensive vortex pair. Finally, variations of the probability density function of the stretch rates with time indicate that the unsteady effect cannot be neglected.

References

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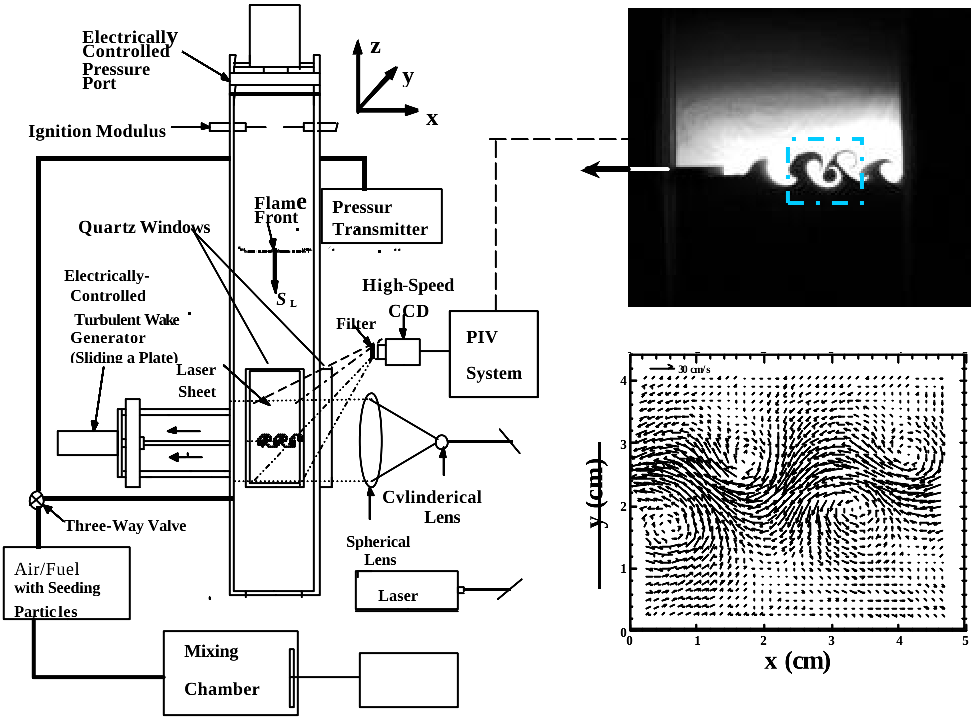

Fig. 1. Schematic diagrams of a decaying turbulent wake burner (left) and its typical unreacting turbulent wake structure using laser tomography with seeding oils only on one side above the sliding plate (right, top). Below is a typical instantaneous unreacting flow velocity map of the corresponding turbulent wake using DPIV.

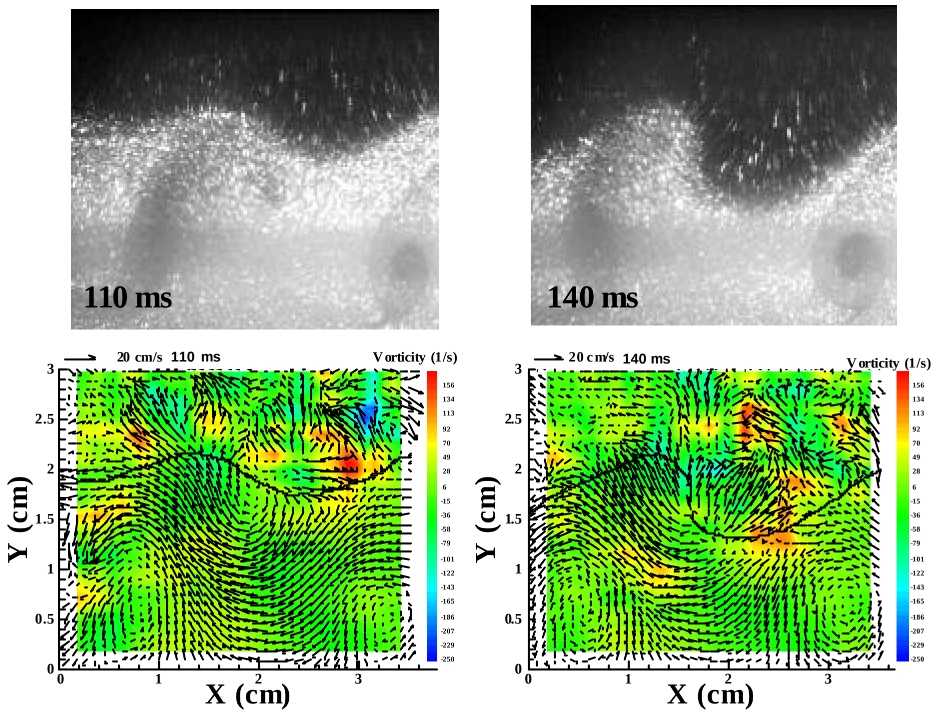

Fig. 2. Top: Original DPIV images of a downwardly propagating premixed CH_4/air (? = 1.45) flame interacting with turbulent wake at t = 110 ms and 140 ms after sliding the plate. Bottom: The corresponding instantaneous reacting flow velocity and vorticity maps of the flame-wake interaction in which the stretched flame fronts (solid lines) are superimposed.