Available online at www.sciencedirect.com

ScienceDirect

Proceedings of the Combustion Institute 36 (2017) 1885–1892

Proceedings of the Combustion Institute

www.elsevier.com/locate/proci

Impact of heat release on strain rate field in turbulent premixed Bunsen flames

Bruno Coriton, Jonathan H. Frank*

Combustion Research Facility, Sandia National Laboratories, Livermore, CA 94551, USA

Received 4 December 2015; accepted 5 July 2016
Available online 10 August 2016

Abstract

The effects of combustion on the strain rate field are investigated in turbulent premixed CH_4/air Bunsen flames using simultaneous tomographic PIV and OH LIF measurements. Tomographic PIV provides three-dimensional velocity measurements, from which the complete strain rate tensor is determined. The OH LIF measurements are used to determine the position of the flame surface and the flame-normal orientation within the imaging plane. This combination of diagnostic techniques enables quantification of divergence as well as flame-normal and tangential strain rates, which are otherwise biased using only planar measurements. Measurements are compared in three lean-to-stoichiometric flames that have different amounts of heat release and Damköhler numbers greater than unity. The effects of heat release on the principal strain rates and their alignment relative to the local flame normal are analyzed. The extensive strain rate preferentially aligns with the flame normal in the reaction zone, which has been indicated by previous studies. The strength of this alignment increases with increasing heat release and, as a result, the flame-normal strain rate becomes highly extensive. These effects are associated with the gas expansion normal to the flame surface, which is largest for the stoichiometric flame. In the preheat zone, the compressive strain rate has a tendency to align with the flame normal. Away from the flame front, the flame – strain rate alignment is arbitrary in both the reactants and products. The flame-tangential strain rate is on average positive across the flame front, and therefore the turbulent strain rate field contributes to the enhancement of scalar gradients as in passive scalar turbulence. Although increases in heat release result in larger positive values of the divergence as well as flame-normal and tangential strain rates, the tangential strain rate has a weaker dependence on heat release than the flame-normal strain rate and the divergence.
© 2016 The Combustion Institute. Published by Elsevier Inc. All rights reserved.

Keywords: Tomographic PIV; Turbulent premixed flames; Strain rate; Dilatation

1. Introduction

The strain rate plays an important role in turbulent mixing by enhancing or suppressing scalar gradients. The turbulence-scalar interaction is strongly dependent on the magnitude of the strain rate tensor eigenvalues, also known as principal strain

* Corresponding author at: P.O. Box 969, MS. 9053, Livermore, CA 94551, USA. Fax: +1 925 294 2595.
E-mail address: jhfrank@sandia.gov (J.H. Frank).

http://dx.doi.org/10.1016/j.proci.2016.07.006
1540-7489 © 2016 The Combustion Institute. Published by Elsevier Inc. All rights reserved.

rates, and their alignments with the scalar gradients [1–5]. In non-reacting turbulent flows, scalar gradients are produced by stretching of the scalar isosurfaces. In reacting flows, heat release introduces additional effects such as dilatation and changes in the gas diffusivity, viscosity, and density. These changes to the fluid properties can in turn affect the strain rate field and its effect on the production of scalar gradients.

In turbulent premixed combustion, the dynamics of the flame–strain rate interaction involve the alignment of the principal strain rates with the flame normal [1]. The flame-normal and tangential strain rates can be expressed as: $S_n = n_i n_j s_{ij}$ and $S_t = [\delta_{ij} - n_i n_j] s_{ij}$, where $s_{ij} = \frac{1}{2}(u_{i,j} + u_{j,i})$ are the nine components of the strain rate tensor and $\boldsymbol{n} = -\nabla c/|\nabla c|$ is the flame-normal unit vector pointing toward the reactants with c representing the instantaneous reaction progress variable. The flame-normal strain rate can be written in terms of the principal strain rates, s_i, as: $S_n = s_1\cos^2\theta_1 + s_2\cos^2\theta_2 + s_3\cos^2\theta_3$, where θ_i are the angles between the strain rate eigenvectors and flame-normal unit vector. The principal strain rates satisfy the relation $s_1 \geq s_2 \geq s_3$. In non-reacting turbulence, $s_1 + s_2 + s_3 = 0$ and the maximum and minimum principal strain rates, s_1 and s_3, correspond to the most extensive and compressive strain rate components, respectively. In reacting flows, the sum of the principal strain rates is non-zero because of dilatation: $\Delta = s_1 + s_2 + s_3 = S_n + S_t$. The flame-normal and tangential strain rates are determined by dilatation and turbulent strain.

The tangential strain rate, S_t, is a key quantity in the transport of scalar gradients [1], critical to the modeling of turbulent premixed flames in the context of Reynolds averaged Navier–Stokes (RANS) and flamelet-based models for large-eddy simulations (LES) [1,4,6–8]. In passive scalar turbulence, S_t is dominantly positive, resulting in the production of scalar gradients. In turbulent flames, an understanding of the turbulent transport of scalar gradients requires analysis of the alignment of the principal strain rates with the flame surface and its relation to heat release.

DNS studies have contributed to our understanding of the strain rate field in turbulent premixed flames. In particular, Swaminathan and Grout [1] established the preferential alignment of the extensive strain rate eigenvectors with the flame normal unit vector, which is a different behavior from that of passive scalar gradients. In moderately turbulent flames, scalar gradients, strain rate, and dilatation are strongly correlated with flame surface curvature [2,3]. However, the preferential alignment of the most extensive strain rate with the flame normal seems to be significantly reduced as the Damköhler number decreases [4,5].

A few experimental studies on turbulent premixed flames [9–11] have investigated the preferential alignment of the strain rate eigenvectors with the flame surface. Velocity measurements have been limited to a single plane and therefore have been unable to assess the three-dimensional orientation of the velocity gradients. In particular, the three-dimensional orientation of the principal strain axes as well as the magnitudes of the divergence and the flame-tangential strain rate cannot be determined from planar PIV measurements. However, cross-plane OH PLIF imaging has been used to determine the three-dimensional orientation of the flame fronts [11]. Ultimately, the development of three-dimensional imaging capabilities is required to fully capture the dynamics of the turbulence-flame interactions. Tomographic particle image velocimetry (TPIV) is an advanced PIV technique that provides instantaneous measurements of all three velocity components within a probe volume [12]. TPIV enables measurements of the nine components of the velocity gradient tensor from which the complete strain rate tensor and the divergence can be derived. TPIV measurements in flames [13,14] have potential to unveil new insights into turbulent combustion [15,17].

Table 1
Non-reacting flow field properties.

u' (m/s)	u'/U	l' (mm)	η (mm)	Re_t	$\langle\lvert s\rvert\rangle$ (s^{-1})
0.62	8.1%	5.0	0.08	250	535

In the present study, we use simultaneous TPIV and OH LIF imaging measurements to analyze the strain rate field in turbulent premixed Bunsen flames. The effects of heat release on the strain rate field statistics are evaluated by comparing measurements in lean-to-stoichiometric CH_4/air flames. The results are presented in the following three parts: (1) strain rate properties of the comparable non-reacting turbulent flow, (2) strain rate-flame alignment and (3) variations of the strain rate across the flame front.

2. Experimental methods

2.1. Flow conditions

Measurements were performed in turbulent premixed CH_4/air flames stabilized on a piloted Bunsen burner of nozzle diameter 36 mm, at a distance of $Y = 50$ mm above the nozzle exit where the influence of the pilot was reduced [18]. An inlet flow rate of 475 LPM was used for the three flames. Turbulence was generated by a combination of two perforated plates housed inside the nozzle. Table 1 lists a series of relevant turbulence properties for a non-reacting jet of stoichiometric reactants measured using 10 kHz TPIV at the same location of measurements in the flames, including the mean and RMS (root-mean squared) axial velocities, U and u', respectively, the integral lengthscale, l', estimated based on the time-

Download English Version:

https://daneshyari.com/en/article/6478124

Download Persian Version:

https://daneshyari.com/article/6478124

Daneshyari.com