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Dynamics of the Flame Flowfields in a Low-Swirl Burner

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Introduction

The concept of using low swirl to stabilize lean premixed turbulent flame was introduced in 1992. Since then, the low-swirl burner (LSB) has become a useful laboratory tool for the study of detailed flame structures as well as turbulent burning speeds. Its main attribute is that the flame is freely propagating and is locally normal to the turbulent approach flow (Figure 1). Therefore, the turbulent flame brush is not influenced by physical boundaries. The capability of LSB to support very lean flames and very turbulent



Figure 1 Low-swirl burner with air jet swirler

flames [1, 2] was further exploited in recent studies to test the validity of the flame regime concept. Using 2D imaging diagnostics (e.g. planar laser induced fluorescence, PLIF, and planar laser induced Rayleigh scattering) our analysis showed that the wrinkled flame regime to be valid at a turbulence intensity level much higher than previously thought [3-5]. This provided experimental verification of a new ‘thin reaction zone’ regime for the Karlovitz number range of $1 < Ka < 10$ ($Ka = (u'/s_L)^{3/2} (l_x/d_L)^{1/2}$) proposed by Peters.

Due to its freely propagating nature, modeling

and simulations of LSB flames are non-trivial. The flame position cannot be specified a priori because it is coupled to the turbulent flowfield and the turbulent flame speed may be required as input. This has not been a significant issue when treating the LSB flame as a close approximation to a 1D premixed turbulent flame. However, to support the development of more robust 3D simulation methods, accurate information on the flowfield dynamics in particular those at the burner exit and the interactions between the core and swirl air flows becomes important.

In the past, velocity measurements in LSB have concentrated on collecting information along the centerline. The objective of this investigation is to conduct a detailed study using particle image velocimetry (PIV) to provide the flowfield information that are more suited to support 3D simulations.

Experiments and Diagnostics

Figure 1 shows the burner used for this study. It employs a perforated plate fitted below the air-swirler to produce turbulence intensity of 10%. This turbulence level is much lower than in previous studies [1-6]. The experimental conditions consist of five methane/air flames with mean flow velocities, U_0 , between 5 and 10 m/s. The experimental were computer controlled with the flow rates of the air supply monitored by a turbine meter, and electronic flow controllers monitored the methane and swirl air flows.

The PIV system has a New Wave Solo PIV laser that produces double 120 mj pulses at 532 nm and a Kodak ES 4.0 digital camera with 2000 by 2000 pixel resolution. The optics captured a field of view of approximately 10 cm by 10 cm for a full view or 60 by 60 for a close-up view of the flame brush. The flow was seeded with 0.3 μm Al_2O_3 particles. Data acquisition and analysis were performed using software developed at NASA Glenn Research Center.

Results

A definition of the swirl number for the LSB was first proposed by Chan et al [7]. It was based on a formula introduced by Claypole & Syred [8]. However, closer review of Claypole and Syred's work revealed that their definition was intended for a special case where the radii of the burner exit and the

swirl jets are identical. For LSB, the swirl jet radius, R_j , is much smaller than the burner radius, R , and Equation 1 is the proper swirl number definition for the LSB of Figure 1.

$$S = \frac{\pi R^2 \dot{m}_j^2 \cos \alpha}{4\pi R_j^2 (\dot{m}_i + \dot{m}_j)^2} \quad \text{Eq. 1}$$

Here, α is the inclined angle of the air jets (20°), and \dot{m} and \dot{m}_j are respectively the total flow rates of the premixture and swirl air. According to Eq. 1 S for the present experiments is 1.4. This is much higher than the $S = 0.6$ criteria of high swirl.

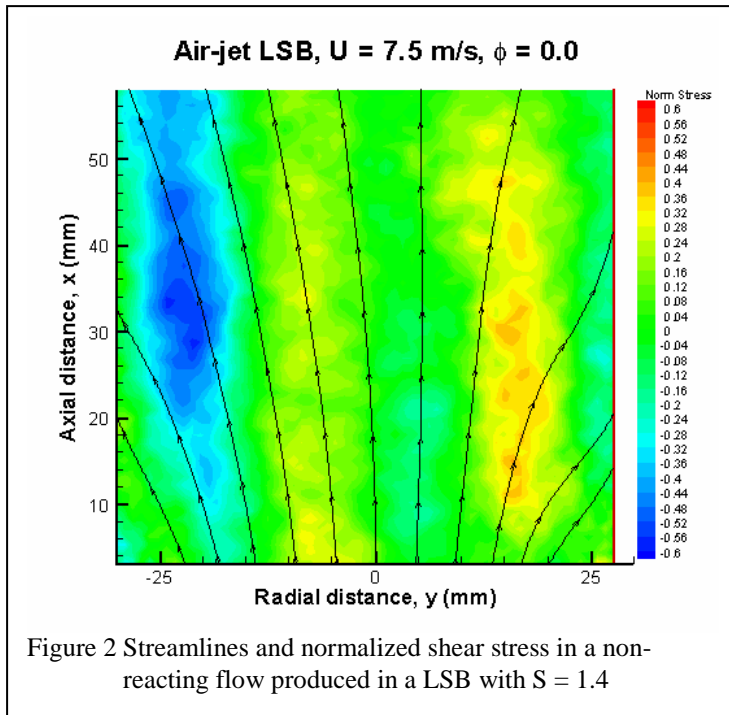
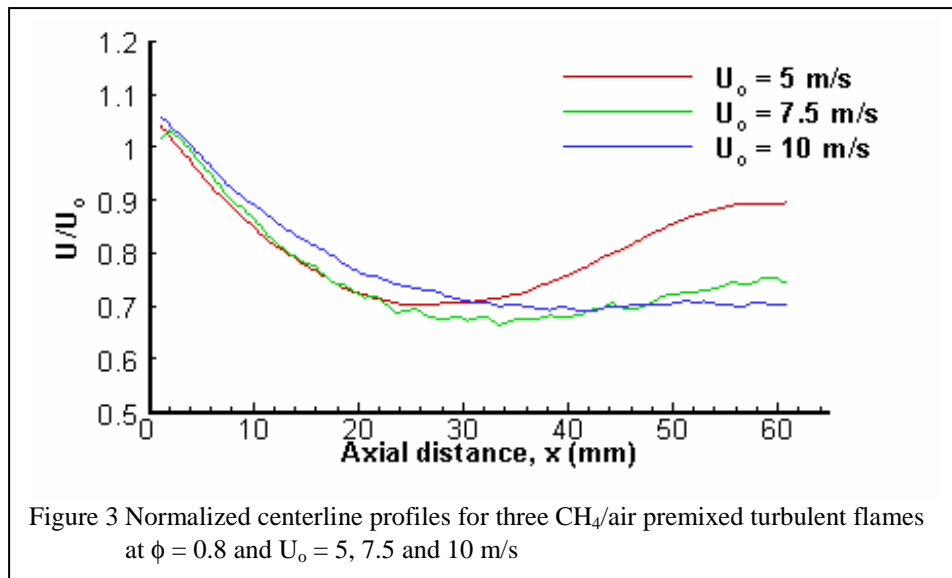


Figure 2 shows the flowlines measured in a non-reacting flow with $U_0 = 7.5$ m/s. Shown in the background are the contours of normalized shear stress $\overline{uv}/u'/v'$. It is clear from the streamlines that the flow is divergent and there is no flow recirculation generated by this burner even though its swirl number exceeds the generally accepted $s = 0.6$ threshold. The $\overline{uv}/u'/v'$ contours show two regions of high stresses of opposite

signs corresponding to the mixing region of the swirl air with the core flows.

Self similarity feature of the LSB flame flowfields is shown in Figure 3. Here axial velocities along the centerlines of three flames all with equivalence ratio $\phi = 0.8$ are normalized by U_0 . In the near field region, of $x < 20$ mm, all three profiles shows a consistent decay. Leveling of the profiles is cause by combustion heat release within the flame brush and the turning points indicate that the flame positions are relatively unchanged with flow velocity. In the farfield region $x > 50$ mm, U remains positive for all three cases. Therefore, these flames do not produce a downstream stagnation point. This feature is different

than the one shown by LSB flames propagating in intense turbulence. Another distinction between these LSB flames and the ones under intense turbulence is that they assume a "w" shape (as seen in Figure 1) instead of a planar shape as seen in [5]. These differences also influence other aspects of the flowfields.



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