

# On Accuracy of the Turbulent Burning Velocity Measured in A Cruciform Burner Using Ion-Probe Sensors

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## Abstract

Turbulent premixed combustion is of great practical importance, since turbulence can increase the burning rate of reactants to a value well above its laminar burning velocity ( $S_L$ ) [1]. A central issue of premixed turbulent combustion is on the effects of turbulent intensity ( $u'$ ) to the turbulent burning velocity ( $S_T$ ) that influence virtually all important properties of premixed turbulent flames.  $u'$  is commonly taken as the rms velocity fluctuation of turbulence. It is extremely difficult to obtain accurate measurements of  $S_T$ , because thermal expansion and heat losses at the flame front may induce both global and local variations of the turbulent flow field. Some averaging procedures have to apply to estimate  $S_T$  which cannot be defined theoretically. Commonly, large scattering data of  $S_T/S_L$  are found even at a fixed  $u'/S_L$  in a given flow configuration [1-3]. Probably, the ideal experimental configuration for benchmark data on  $S_T$  is that a premixed flame propagates downwards through a 3-D fully developed homogeneous turbulence, similar to that assumed by direct numerical simulation [4]. This was recently achieved using a cruciform burner [3,5]. A long vertical cylindrical section of the cruciform burner was used to generate a downward propagating premixed flame, while a large horizontal section equipped with two identical counter-rotating fans and perforated plates at each end was

used to create near-isotropic turbulence. This cruciform burner can provide statistically stationary propagation of turbulent premixed flames with a wide range of mixture conditions and turbulent intensities [3,5]. Moreover, the flame propagation in the cruciform burner is free from the ignition source and flame-turbulence interactions can occur over many turbulent integral lengthscales in all three directions.

We have measured turbulent burning velocities of methane-air and propane-air mixtures over a wide range of equivalence ratios and turbulent intensities ( $u'/S_L$  up to 50) using a pair of ion-probe sensors [3,5]. The two ion-probe sensors were positioned at “a” and “e” with a separation distance of 20 cm, as shown in Fig. 1 (measurement I). These results are compared with other experimental data using different burners [1,2,6,7] and they can be fitted into a general correlation of the form  $(S_T - S_L)/u' \approx 0.05 Da^{0.61}$ , where  $Da$  is the Damköhler number. This correlation is found to be better than previous correlations, which covers both corrugated flamelet (large  $Da$ ) and distributed (small  $Da$ ) regimes. However, some questions remain to be answered. Do the ion-probe sensors actually measure the turbulent burning velocity (not the turbulent flame speed)? In other words, can the gas velocities ahead of propagating turbulent flames be neglected? What are the effects of pressure rise due to turbulent burning in the cruciform burner on  $S_T$  measurements? This work addresses these questions and validates the accuracy of our  $S_T$  measurements using two ion-probe sensors.

As shown in Fig. 1, there are four different arrangements of two ion-probe sensors to be chosen for turbulent flame speed measurements, including measurements (I), (II), (III) and (IV) which correspond to positions “a-e” (20 cm apart), “a-c” (10 cm), “c-e” (10 cm) and “b-d” (10 cm), respectively. The measured turbulent flame speeds at these four different arrangements are respectively denoted as  $S_{F1}$ ,  $S_{F2}$ ,  $S_{F3}$  and  $S_{F4}$ . In this study, we use stoichiometric methane-air mixtures with two different fan frequencies (30 and 100 Hz) to test the accuracy of  $S_T$  measurements. Under the same experimental conditions, at least five runs are repeated for each

of four different measuring arrangements. It is found that  $S_{F2} > S_{F1} \approx S_{F4} > S_{F3}$ . The turbulent flame is accelerating near the upper portion of the interesting region (“a-c”), whereas it is decelerating at the lower portion (“c-e”). There are gas velocities ahead of turbulent propagating flames at the upper and the lower portion of the central uniform region in the cruciform burner. Both gas velocities at the upper and the lower portion of the central uniform region have opposite signs with essentially the same magnitude, in which  $(S_{F2} - S_{F4})/S_{F4} \approx (S_{F4} - S_{F3})/S_{F4}$  with only 0.4 % difference. Thus, the gas velocities can be neglected because of the cancellation, when measurements (I) and (IV) are applied. It was the turbulent burning velocity that we actually measured for which  $S_{F1} = S_T$ . Concerning the pressure effects, four, six, and ten pressure release valves are used independently (see Fig. 1). In each case, we measure the evolution of pressure changes and turbulent burning velocities as a function of the fan frequency ranging from 0 to 127 Hz for both stoichiometric methane-air and propane-air mixtures. By comparing values of  $S_T$  using 4 valves with that when 10 valves are used, it is concluded that the pressure rise in the cruciform burner has little influence on values of  $S_T$  and thus validates our previous  $S_T$  measurements.

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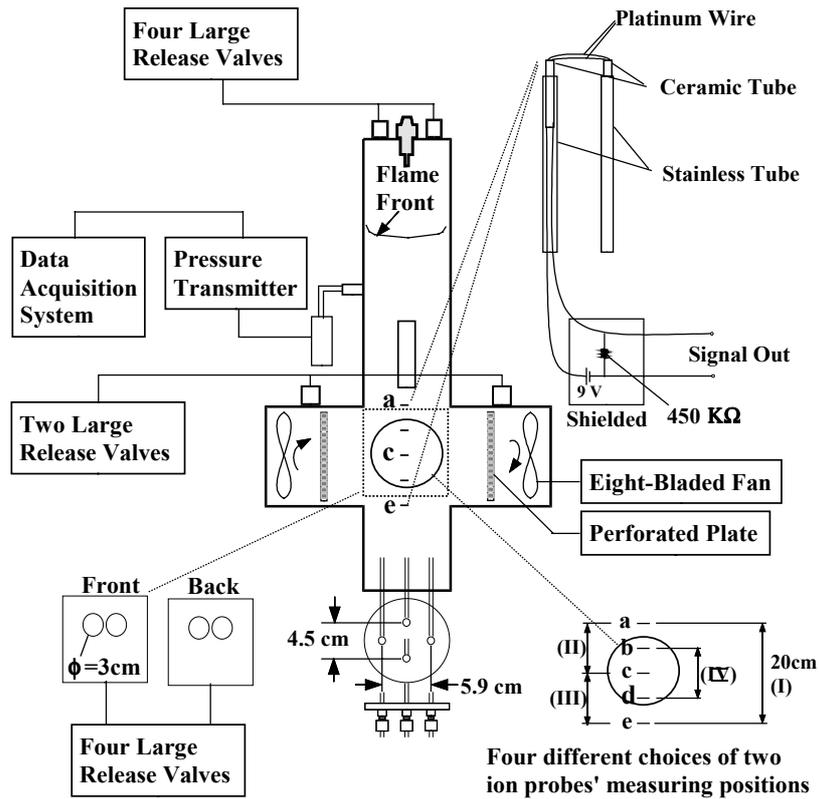


Fig. 1. Schematic diagrams of the cruciform burner with four different arrangements of ion-probe sensors for turbulent burning velocities measurements and the arrangement for pressure measurements including ten pressure release valves.