PIV measurements and laminar flame speeds

1. OBJECTIVE

The objectives of this experiment are:

- To introduce the particle image velocimetry technique
- To acquire data on a classic opposed strained flame configuration
- To analyse the data to obtain laminar flame speeds

2. INTRODUCTION

Laminar flames are thin reaction zones where reactions take place. These form the basis for turbulent flames. Steady laminar premixed flames are produced when the velocity of the thermal and kinetic front in a laminar flow propagates at the same and opposite rate as the incoming flow of reactants. This is the case in a stabilised Bunsen flame, premixed flame, and in the present case, a strained stabilised flame created by lighting a mixture in a strained flow field. These flames are building blocks for flames in turbulent flames, which also experience strain.

In this experiment, we would like to measure the velocities of the incoming flow by seeding the flow with very small alumina particles, which can easily follow the flow. The flow field is determined, and a reference flame speed is determined. A theory of propagation of laminar flames in strained flame has been developed, so that if the velocity and strain are known at the centerline, it is possible to determine the expected laminar flame velocity from a twin or impinging flame [1,2]. Further, it is also possible to determine the reference flame speed at the particular strain. These values can be compared to calculations using well-established methods

Figure 1 shows typical velocity vectors obtained from an experiment with an impinging flow. We will be producing similar plots in a symmetrical flow. The reference velocity S_{ref} obtained as the minimum axial velocity before flame acceleration is taken as a reference velocity at a given strain a = 2 K. These can eventually be extrapolated through several methods to a

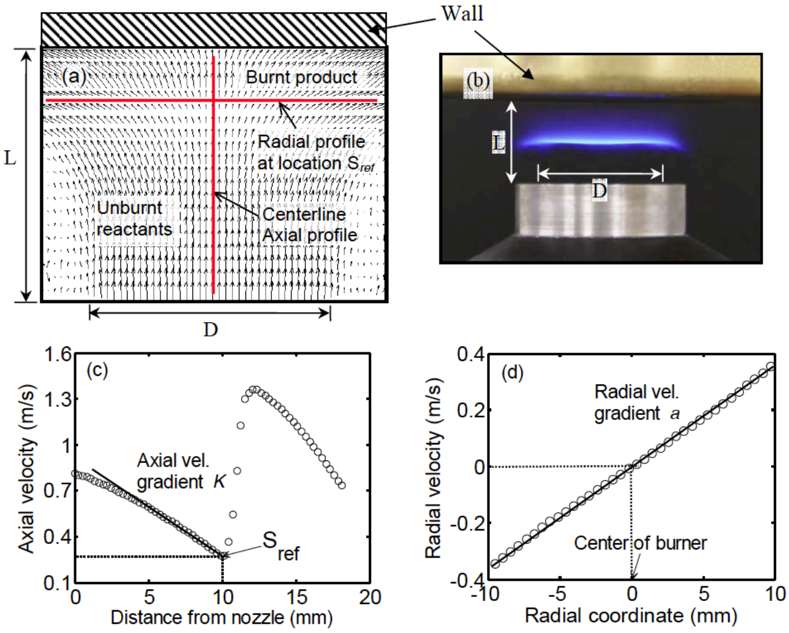


Figure 1. Typical velocity profiles measured in an impinging flow system. (a) mean velocity vectors corresponding to the impinging flame flow, (b) photo showing the impinging flame onto a stagnation wall (which serves as a symmetry plane), (c) mean axial velocity extracted at the centerline, leading to a

reference velocity, (d) radial velocity, often used to determine the strain or velocity gradient, as more precise than the axial velocity gradient.

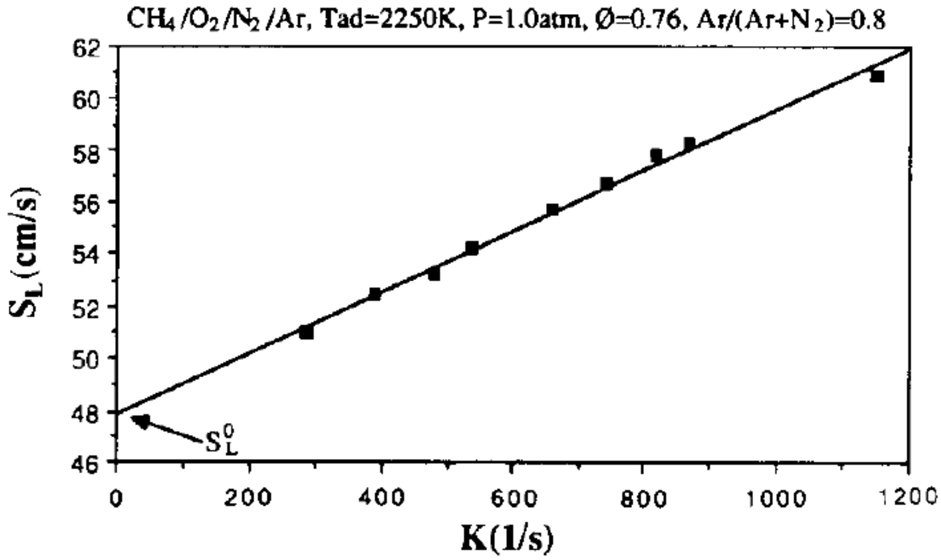


Figure 2. Typical linear extrapolation of strained flame to obtain laminar premixed flame [1].

3. METHOD

3.1 Apparatus

We will be using an opposed flame setup for the experiment and premixed metered methane-air fuel mixtures at a given equivalence ratio. The burner consists of two symmetrically placed converging nozzles with 22 mm exit diameter shrouded by a 3 mm wide annular nitrogen flow to prevent air entrainment from disturbing the flame. An in-house fluidized bed seeder is employed for PIV velocity measurements using hydrophobic amorphous Silica with a size distribution in submicron range (~ 0.3-0.4 μm) and a density of 0.05 g/cm^3.

3.2. PIV description and technique

A dual laser head, double pulsed Nd:YAG laser (Litron Lasers:NANO-L-200-15 PIV) is used to generate a laser light sheet with a thickness of ~ 0.5-1.0 width x 30 mm height to illuminate the uniformly dispersed particles in the flow. The laser energies are around 40 mJ/pulse at 532 nm with a 4 ns pulse width.
The light scattered from the seeding particles in the flow was recorded by a 12 bit, 2048 x 2048 pixels Imager Pro X 4M CCD camera with a pixel pitch of 7.4 x 7.4 μm at double frame mode of 4.5 Hz. The camera was fitted with a 60 mm/F2.8 Nikkor lens coupled with an optical band pass filter centered at 532 nm to minimize the effect of flame luminosity. The timing of the laser system and camera is synchronized by a LaVision. Programmable Timing Unit Version 9 (PTU 9). The commercial software Flowmaster from LaVision was used for image acquisition and the analysis of image pairs. The field of view was fixed at 35 x 35 mm with a magnification factor M equal to 0.43.

3.2 Experimental Procedure

SAFETY WARNINGS

- **Safety glasses to be worn by all in the experimental area**
- **Laser googles for 532 nm with the appropriate filter density to be to be worn during alignment and full energy experiments**
- **Never change the apparatus without consulting the demonstrator.**
- **Never leave an open flame unattended. Be careful with paper sheets, sleeves and long hair!**

Part 1. DaVis software introduction

(lecture)

Part 2. Data acquisition

(These will be done in smaller groups)

1) Set the air flow rate to the calculated value;
2) Set the Nitrogen flow rate to 50 SLPM;
3) Set the methane flow rate to the calculated value, ignite the flame using the torch provided;
4) MAKE SURE LASER GOGGLES ARE WORN. Turn on the laser. Start data acquisition. 100 images for each case;
5) Turn off laser; turn off methane flow; turn off air flow;
6) Demonstrator checks the raw data quickly. If there is no problem, repeat all steps for the next condition.

3.3 Data reduction

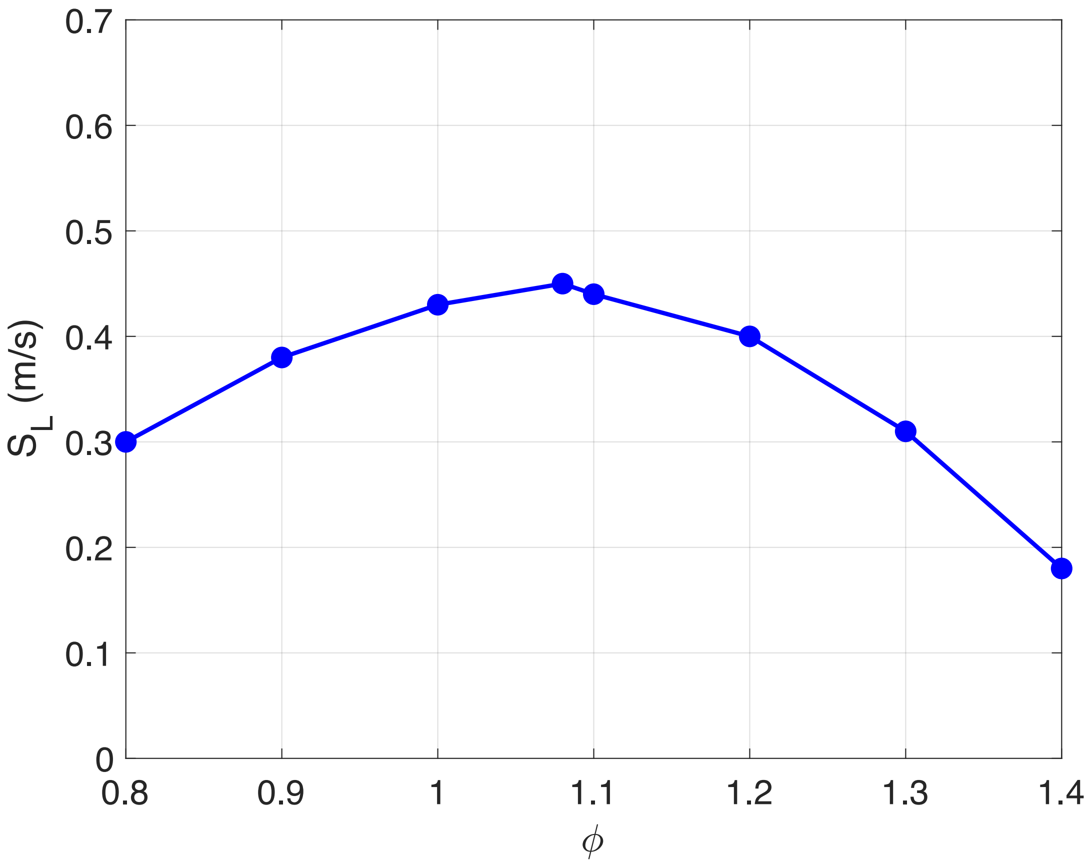
Demonstration of data reduction in the laboratory

4. Results

Make a note of the present results for comparison with the laminar flame speed results in the other experiment: which one do you think is more accurate and why?

References

1. D.L. Zhu, F.N. Egolfopoulos, C.K. Law, Twentieth Symposium (International) on Combustion, The Combustion Institute, Pittsburgh (1984), 1537-1545
2. C. M. Vagelopoulos, F. N. Egolfopoulos, and C. K. Law, Proc. Combust. Inst., vol. 25, pp. 1341-1347, (1994)


0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.8
0.9
1
1.1
1.2
1.3
1.4
S_L (m/s)
ϕ