Turbulence and Velocity Induced by Combusting Impinging Jets

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Abstract

LDA studies of the turbulence and velocity induced by combusting jets have been carried out. Extensive and detailed flow characteristics of two combustion modes (disc and ring flames) under identical nozzle flow conditions have been measured. The data have shown dramatic difference in flow structures between the two combustion modes. Clear evidence has been provided by the measurement to prove the previous conjecture that the ring flame occurs on the opposite ramp side to the stagnation region of the radial velocity profile. The measurements also reveal that combustion can only occur beyond the maximum wall jet velocity layer and further away from the plate surface in the case of the ring flame jet.

Introduction

Recently, it has been observed that multiple combustion modes can exist for turbulent premixed impinging jets [1-3]. Under the same nozzle flow conditions, up to four alternative combustion modes can be established depending on the initial ignition location. LDA measurements have been carried out to investigate the flow characteristics so that the mechanism of the various observed modes can be understood. The multiple combustion modes under identical nozzle flow conditions also provide excellent opportunities to study turbulence and velocity induced by combustion since they all have the same inlet boundary conditions.

In this paper, results of LDA studies of turbulent impinging jets are presented. Particular attention is focused on the disc and ring flame jets.

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Experimental Set up

The burner and the flow measurement system are explained in detail in reference [1]. Only a very brief description is given here. Basically the burner consists of a reactant jet impinged on a steel plate of 0.3 m in diameter. The burner nozzle is installed with a turbulence generator, which is a perforated disc with blockage ratio of 0.69. The holes on the disc are 0.003 m in diameter. The burner and the plate are mounted on a computerised 3-D traverse gear so that the whole flow field could be scanned automatically. Unlike other researchers [4-7] who chose a curved flame impinged plate to facilitate the optical access of the laser beam, the plate used in this experiment is flat. This is an important variation in view of the known sensitivity of turbulence to weak streamline. To prevent the plate from blocking the laser beam, the laser system is tilted at an angle so that two of the laser beams are parallel with the plate surface. In this manner, it is possible to measure the velocity as close as 1 mm to the plate surface.

The present studies focus only on one particular flow configuration. The mass flow rate is 6.03E-03 kg/s and the fuel-to-air equivalence ratio is 1.24. The ratio of nozzle exit to plate distance (H) to the inner diameter of the nozzle (D) is H/D = 3.

LDA system consists of a 5-Watt Argon Ion laser, a telephoto lens type signal collection system and a TSI data processing system.

Results and Discussion

Three vector maps have been shown in Fig. 1, which correspond to a cold flow, the disc flame and the ring flame jets under the same nozzle mass flow rates. In the plot, the arrowhead marks the spatial position of each vector. The disc flame and ring flame jets also have the same fuel to air equivalence ratio. By direct visualisation, the radius of the disc flame is approximately 50 mm and the inner radius of the ring flame is also approximately 50 mm. From the figure it is obvious that combustion has induced much thicker wall jets compared with the equivalent impinging cold jet. Another immediately observable feature is the buoyancy created by combustion beyond the edge of the plate.

Figure 2 is a plot of the radial velocity profiles of the cold jet, disc flame and ring flame. Figure 2(a) is a plot of the radial velocity 1mm away from the plate. It can be seen that the velocities increase almost linearly away from the stagnation point initially with the disc flame jet having the highest rate of increase. Then a peak is reached at the same radial position for all the three jets. For the disc flame jet, the maximum velocity is significantly higher due to the presence of combustion. Though it is only 1 mm away from the plate, the radial velocity is already very high and so is the velocity gradient. It seems that no combustion can be sustained at this distance from the plate for the ring flame jet since no velocity increase is observed until it is close to the plate edge. The velocity increase near the plate edge is actually caused by buoyancy effect as we can see from Fig. 1. The radial velocity profiles at 5 mm away from the plate is shown in Fig. 2(b). It can be seen that the radial velocity of the ring flame jet starts to increase after reaching a local maximum at the same spatial location as the cold jet. This suggests that combustion is occurring at this distance away from the plate surface. Shown in Fig. 2(c) is the radial velocity profiles 11 mm away from the plate. It can be seen that the velocity almost halved at the same spatial location if compared with those values at 1 mm away from the plate. The radial velocity of the disc flame reaches its peak at around 0.05m radial distance. The location of minimum radial velocity for the ring flame jet marks the inner radius of the ring flame and combustion makes the radial velocity increase again until the second peak is reached. It is interesting to note the velocity profiles superimposed together over the later part for the disc and ring flame jets. This may be explained by the fact that both the combustion modes have the same fuel to air equivalence ratio and nozzle exit velocity. As a result, the final heat release and gas production should be very close. In other words, the velocity profiles should be similar when combustion has ceased for both the modes. From the figure it can also be seen that the ring flame occurs on the opposite side of the velocity 'ramp' relative to the stagnation point as suggested in reference [2]. However it is unexpected that the radial velocity very close to the wall has such a high value and combustion for the ring flame mode only occurs further away from the plate. Examples of turbulence intensities along the radial direction at 5 mm away from the plate are shown in Fig. 3. It can be seen that combustion does not produce turbulence intensity.

Concluding Summary

Detailed LDA studies of turbulent impinging jet have provided much physical insights into the combusting jets under various combustion modes. It is observed that there is no combustion taking place very close to the plate for the ring flame jet. The experimental results have proved the previous conjecture of ring flame forming mechanism. Combustion induces significant near wall flow acceleration for the disc flame jet. However, it seems that combustion does not generate very noticeable extra turbulence.

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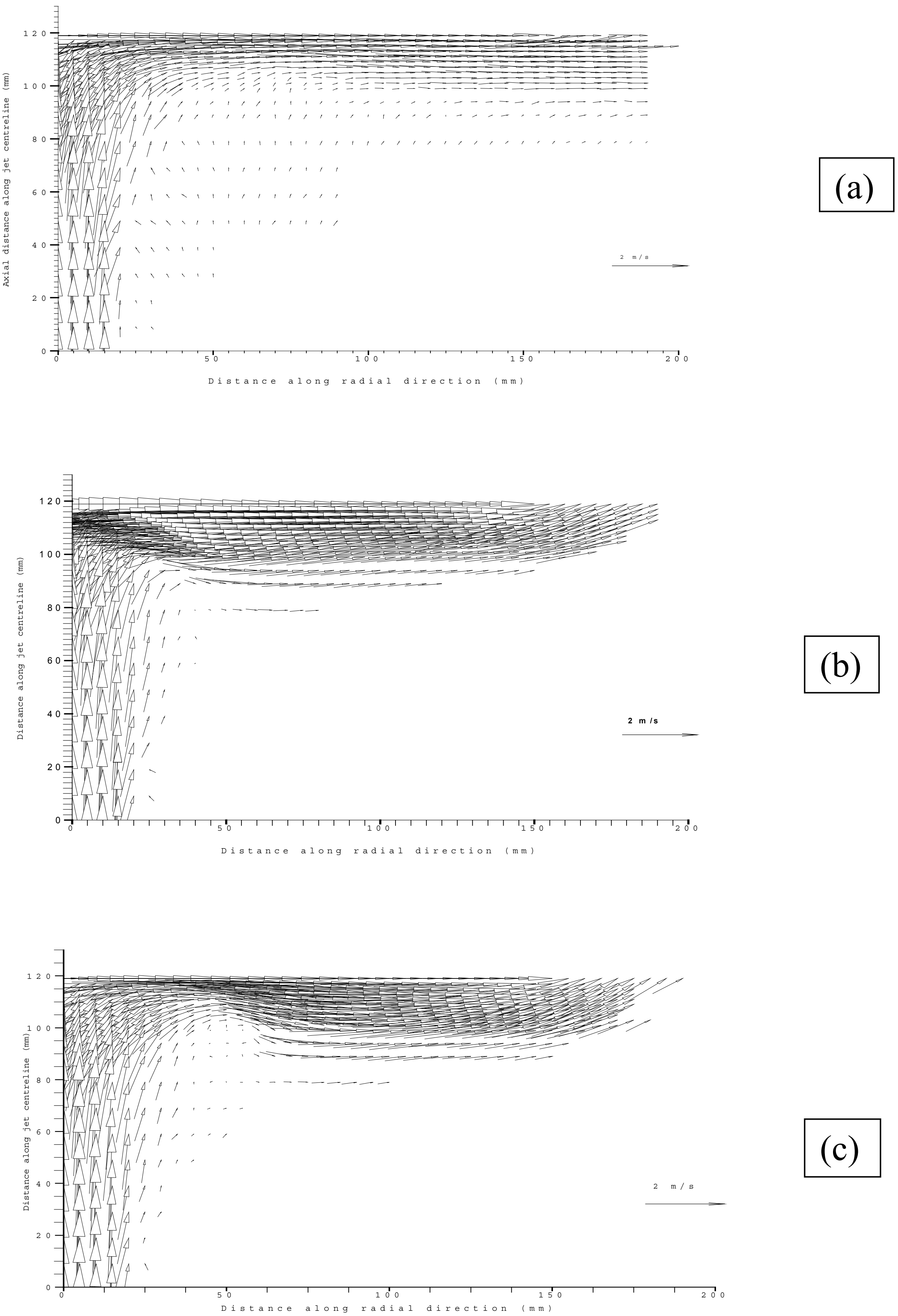

Figure 1: Vector maps of cold jet, disc flame jet and ring flame jet.

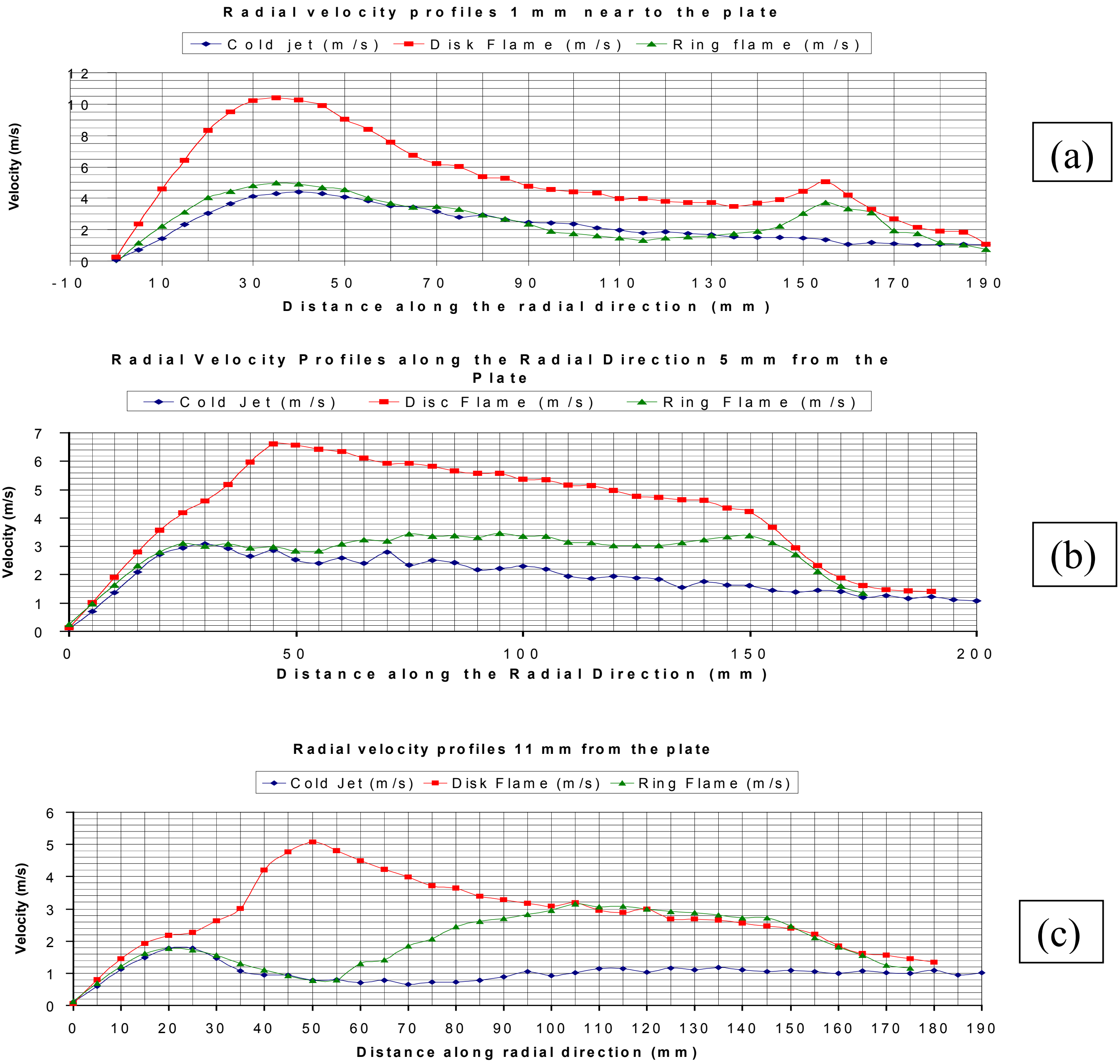

Figure 2: Radial velocity profiles at three distances away from the wall.

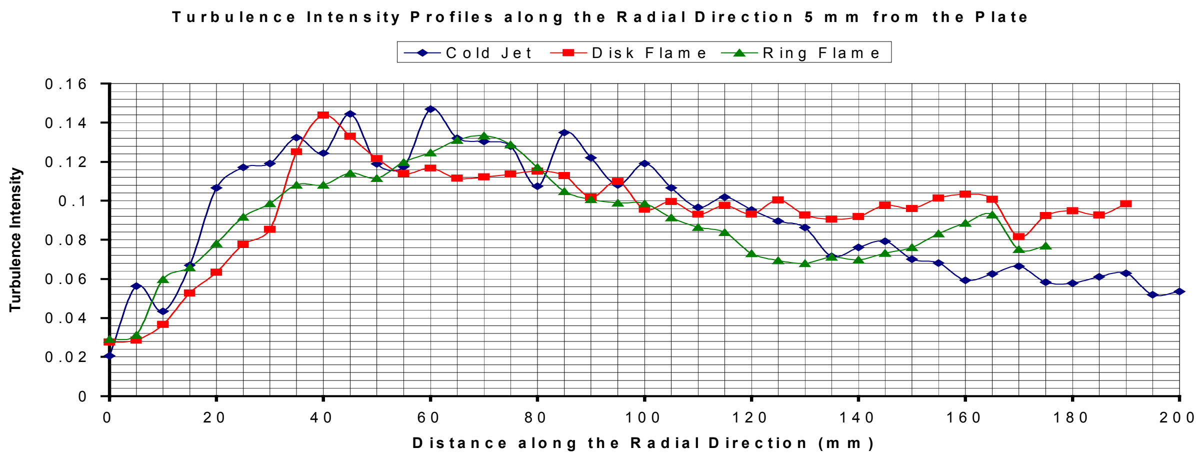

Figure 3: Examples of turbulence intensities in the radial direction.