7 Conclusion and Scope for Future Work

7.1 Conclusion

In the present thesis, an experimental facility was developed to study free convection around inclined flat plates using the PIV technique. The inclination of the plate varies from horizontal to vertical and is subjected to various uniform heat fluxes. The flow characteristics over the plates were investigated for various inclinations and heating conditions. Based on the inclination angle of the plate, the present work is divided into three sections: vertical ($\phi = 90°$), inclined ($30° \leq \phi \leq 60°$), and horizontal and slightly inclined to horizontal ($0° \leq \phi \leq 10°$).

I. A free convection boundary layer that forms over a vertical flat plate is investigated under various heating conditions and is described in chapter 4. The use of PIV for measurements within the boundary layer and/or near wall measurements poses challenges because of wall reflections, steep velocity gradients, presence of a shadow region and low seeding density. Therefore, special measures have been taken to overcome the challenges that near-wall measurements pose by painting the surface with matt black, employing background elimination technique, using suitably sized seeding particles and their concentration. It was found that the ensemble correlation wherein wall is aligned with the interrogation area, gives better results close to the wall. For the experimental condition employed, it is found that the velocity boundary layer consists of a thin inner layer ($\sim$2 mm) and a thicker outer layer ($\sim$15 mm). The thicknesses of the inner and outer velocity boundary layers increase along the streamwise direction and decrease with the applied heat flux.

II. A study of the free convection phenomenon over an inclined plate whose inclination varies from 30° to 60° from horizontal has been presented in chapter 5. It is found that the laminar to turbulent transition occurs when the inclination of the plate $\phi \leq 45°$ and only laminar flow appears over the plate for the range of heat flux considered when the inclination angle is more than 45°. The region where the velocity transition occurs is identified based on the flow structure obtained by the PIV technique. Four criterion for the identification of onset of transition that have been employed are - (i) variation of the overall VBL thickness, (ii) inner VBL thickness, (iii) maximum streamwise velocity in the VBL and (iv) wall shear stress. A sharp deviation of these parameters from the laminar regime is an indication of onset of velocity transition. It is observed that the initiation of transition is first seen in the overall VBL thickness. However, variation in maximum streamwise velocity in the VBL is the most appropriate method for the identification of onset of transition. It is found that the streamwise distance of the onset of velocity transition from the leading edge decreases with the increase of heat flux and increases with the inclination angle. The highest value location of onset of transition $x_t = 136$ mm, is found at $\phi = 45°$ and $q_w'' = 100$ W/m^2 and the corresponding Ra_x^* is 7.27×10^8. The smallest value of x_t obtained for $\phi = 30°$ and $q_w'' = 5000$ W/m^2 is 41 mm which corresponds to Ra_x^* of 3.09×10^8. In the laminar regime, the inner VBL thickness decreases with the increase in inclination angle and also with the heat flux. Also, the wall shear stress increases with the increase of plate inclination and the heat flux in the laminar regime.

III. Our attention is focused on free convection above a horizontal or slightly inclined to horizontal heated plate in chapter 6.

In this case, three distinct flow patterns are discernible when $0° \leq \theta \leq 10°$: (i) laminar flow (ii) transition flow and (iii) plume. For the case of the horizontal plate, it is seen that in the laminar regime, the fluid close to the surface flows from both ends of the plate towards the centre. After some distance, the laminar flow gets transformed into transitional flow which is manifested by increase in boundary layer thickness and increase in u-velocity. Finally, a plume rises from the far end of the transition region. When the plates are inclined, the position of these three regions gets displaced over the plate. It is found that the onset of transition gets delayed with increasing inclination angle and occurs earlier with an increase of heat flux. The maximum value of the location of onset of transition from leading edge per unit plate length is 0.21 and was obtained for $\phi = 10°$ and $q_w'' = 500$ W/m^2. On the other hand, the transition length increases with the heat flux and also with the inclination angle. The maximum value of transition length per unit plate length is 0.58 and it was obtained for $\phi = 10°$ and $q_w'' =$ 2000 W/m^2.

The details of VBL is discussed with help of the variation in u-velocity. It is observed from the velocity profile within the VBL, that the inner VBL thickness decreases in the laminar regime and increases in the transition regime. Also, similar to the case of inclined plate, the inner VBL thickness decreases with the increase in inclination angle and also with the heat flux in laminar regime.

The details of the buoyant plume regime have been discussed by using the variation of v-velocity. It was found that at a particular height from the plate, the centre line velocity increases with the heat flux and decreases with the inclination angle. The plume width has also been estimated based on the criteria of 10% of centre line velocity. It is observed that plume width first decreases (due to necking) and then increases in the vertical direction (due to horizontal diffusion). Also, an increase in heat flux and inclination angle causes an increase of plume width at a particular height from the plate.

As the flow moves from both sides of the plate, it is observed that at a certain distance from the both ends, the two flows interact, then separate off the plate to form a plume. This distance from the leading edge, termed as the 'lift-off' point is found to be solely determined by the inclination angles and is unaffected by the heat flux.

7.2 Scope for future work

- In the present work, a flat plate of aspect ratio 1.5 was utilized for the experiments. The effect of various aspect ratios on the flow structure needs to be further investigated. Also, to obtain the transitional and turbulent flow structure at every value of inclination angle, the experiments need to be conducted for larger plate sizes than what were used in the present work. It would be helpful in analyzing various turbulent parameters in external free convection over a flat plate.
- The flow conditions in the present work were 2-D by employing fences over the plate. Removing the fences would generate a 3-D flow which would be interesting to study vis-à-vis the 2-D flow studied in the present work.
- A Direct Numerical Simulation (DNS) of the flow over an inclined plate in free convection and its validation with the current experimental results needs to be done. It would be useful in the determination of some parameters which is difficult to measure experimentally.