FLUID FLOW IN AN ENCLOSURE WITH COLLIDING BOUNDARY LAYERS

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ABSTRACT
This paper reports velocity measurements carried out in a water-filled enclosure with localised heating and cooling of one side wall. The enclosure represents a scale model of a small room with a heater located on one of the side walls, below a window. This results in a colliding boundary layer situation. The experiments were performed for Rayleigh numbers of the order of 10^{11}. Measurement of fluid velocity was done with a particle tracking method and the data processing was done with DigImage™ software.

1. INTRODUCTION
In the study of natural convection in enclosed spaces, fluid velocity and temperature distribution are important parameters. These type of studies are required to optimise the building design in regard to thermal comfort and energy efficiency. Euser et al [1978] and Sadowsky et al [1987] have reported similar studies using experimental techniques. The work by Gatheri et al [1993] is more relevent to this paper as they have modelled the colliding boundary layer situation numerically. The entire geometry of the enclosure considered by them is similar to the geometry considered in the present study. This paper reports experiments carried out to measure velocities in a scale model of a room with localised heating and cooling. A heater mounted below a cold window makes the situation interesting with the collision of the two boundary layers. This situation is difficult to model numerically at high Rayleigh numbers.

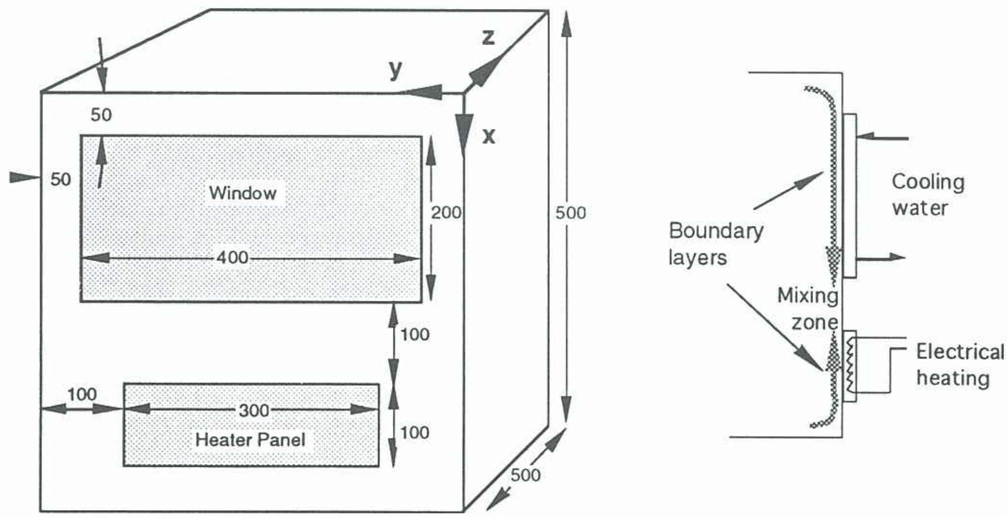

Figure 1. DIMENSIONS OF ENCLOSURE AND SCHEMATIC OF COLLIDING BOUNDARY LAYER SITUATION.

2. EXPERIMENTAL APPARATUS

The apparatus used was a scale model of a room with water as the heat transfer medium. The model dimensions were decided by matching dynamic similarity between the model and the room. Rayleigh number based on enclosure height and the temperature difference between hot and the cold plates was the scaling parameter. The glass and acrylic model measured 500 mm cubed internally with other dimensions as shown in the Figure 1. The heater plate in the model was in the form of four cartridge elements mounted in an aluminium plate 30 mm thick. Four heating elements of 800 watts each were selected to maintain a uniform temperature of the panel at 60°C. The window was in the form of a water-cooled copper plate heat exchanger. The inlet temperature of the circulating water was maintained constant within ±0.5°C by means of a small refrigeration plant. The details of these components are given in Kulkarni and Cooper [1995]. Provision was made to record the surface temperatures of heater and window, cooling water inlet and exit temperatures and the input power to the heaters. The walls of the enclosure were insulated with 25 mm of polystyrene foam sheet to maintain adiabatic boundary conditions.

2.1 Velocity Measurement - Hardware

Measurement of fluid velocities in natural convection poses many challenges. When water filled models are used velocities are low and conventional techniques such as hot wire anemometry are not appropriate. A particle tracking system was developed successfully which, in combination with the commercial DigImage™ software package, gave the velocity plots in the required form. Stevens and Coates [1995] have also reported the use of this technique for the measurment of fluid velocity.

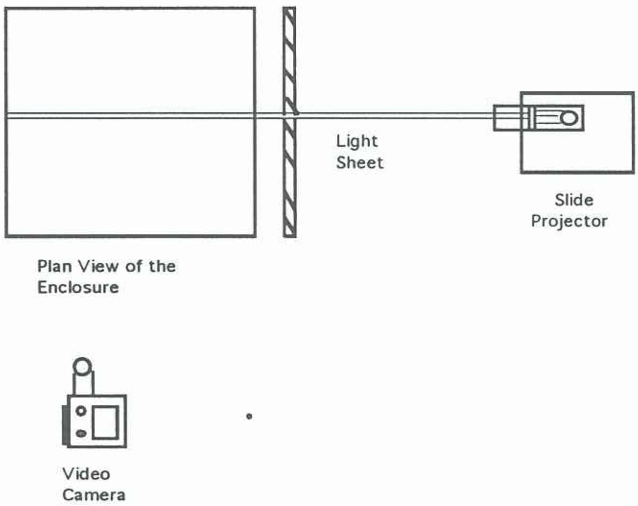

Figure 2. SCHEMATIC OF DATA ACQUISITION HARDWARE

The technique uses small neutrally buoyant particles mixed in water. The density of the particles is matched to the density of the fluid medium by adding a quantity of salt to ensure neutral stability of the particles which are then used to track the flow. In the present study Pliolite particles were used as tracers. These particles were available from a plastic manufacturer as a bulk mixture of different sized particles. Particles of 220-350 microns were used in the final trials selected after initial experiments. The movement of the particles was recorded in specific planes by illuminating the model with a 5 mm thick light sheet from a 35 mm slide projector and videoing the particles. The video film was then processed using a computer controlled video recorder, a frame grabber and a particle tracking software package (DigImage™) developed at the University of Cambridge, U.K. The data acquisition hardware and software systems are shown schematically in Figures 2 & 3. Four sets of data were recorded at a constant window temperature of about 12°C and the heater temperature was in the range of 40° to 60°C. These datasets were taken at least 48 hours after starting the experiments.

2.2 Velocity Measurement - Software

The video recording of the particle movement in a specific plane was input to the (DigImage™) software. The software included a wide range of features including digital control of the video recorder enabling a very large number of video frames to be processed whereby an extremely reliable estimate of the temporally averaged flow field in a given plane could be obtained. The software operates in two parts. In the first part, tracking videos are processed to obtain tracking data files. The second part takes the input from these data files and produces the temporally averaged flow field plots. These plots can be produced for a variety of options of grid size, averaging functions and time intervals.

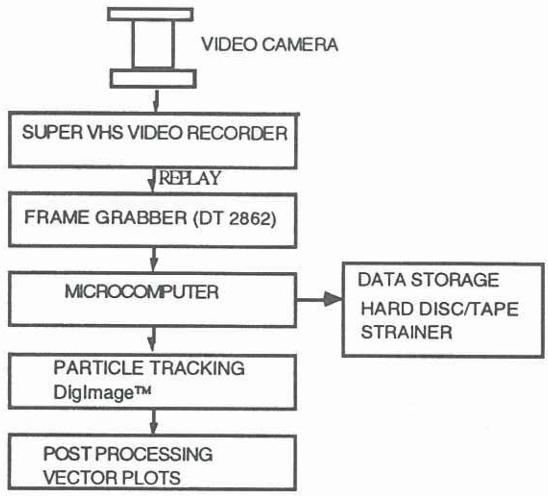

Figure 3. SCHEMATIC OF DATA ACQUISITION SOFTWARE SYSTEM.

3 RESULTS AND DISCUSSION

Figure 4 shows a typical velocity plot at Ra = 1.7×10^{11} for y=250 mm plane. The average heater and window temperatures for this set of readings were 51.7°C and 12.7°C. The velocity vectors shown here represent the mean velocities averaged over a period of 240 seconds. The maximum velocity in the enclosure was observed close to the active wall. The other parts of the enclosure were relatively quiescent. The flow field was found to be very complex near the boundary layer collision region. The boundary layers on both the heater and window were observed visually to be laminar for all experiments undertaken. Using the relatively course mesh shown here for presenting velocity plots for the entire enclosure it is not possible to show the details of the boundary layer flows which were of the order of 3-4 mm thick. However, the particle tracking system did identify the particles in the two boundary layers and velocity profiles in this region can be studied if necessary using a fine grid. The resultant flow from the collision of the two boundary layers does not take place horizontally but flows upward. This is somewhat different from the results predicted by Gatheri et al [1]. A phenomenon which has been previously reported as "fingering" by Humphrey et al [1985] was observed in the collision region which resulted in locally unsteady flows. The upward direction of the mixed flow results in weaker stratification in the upper half of the enclosure and the two cold plumes coming down from the part of the window which is not covered by heater plate play important roles in the production of a moderately stratified lower half of the enclosure.

4 CONCLUSIONS

This paper reports velocity measurements carried out in a cubicle enclosure with colliding boundary layers. Velocity measurements were performed using a particle tracking technique. The fluid flow was much complex and three diomensional in the mixing region. The resultant flow and mixing of two boundary layers and the two plumes coming down from the window not covered by the heater play an important role in determining the stratification of the enclosure.

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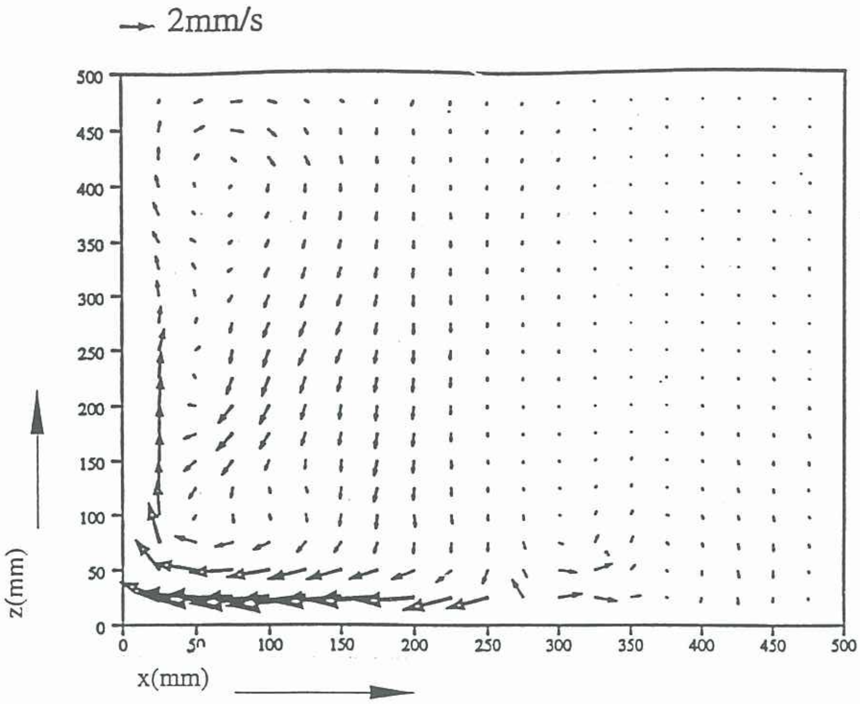

Figure 4a. VELOCITY PLOTS FOR Y=250mmPLANE

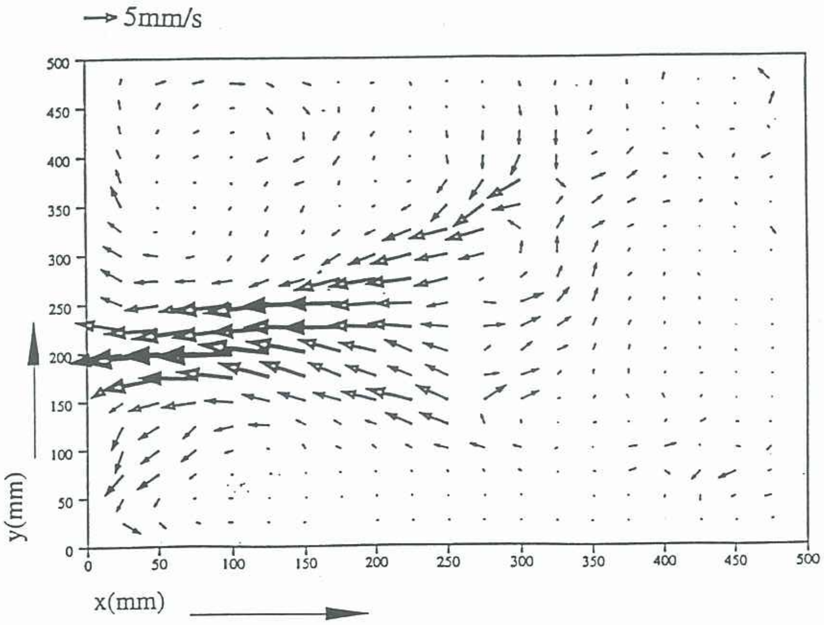

Figure 4b. VELOCITY PLOTS FOR Z=20mm PLANE