Kelson, Neil A. & Reizes, John
(1990)
Natural convection in rectangular cavities at high Rayleigh number. In
3rd Australian Natural Convection Workshop, 6-7 December 1990, Monash University, Clayton, Vic.

NATURAL CONVECTION IN RECTANGULAR CAVITIES AT HIGH RAYLEIGH NUMBER.

N.A. KELSON & J.A. REIZES

Natural convection in rectangular two-dimensional cavities with differentially heated side walls is a standard problem in numerical heat transfer. Most of the existing studies has considered the low Ra laminar regime. The general thrust of the present research is to investigate higher Ra flows extending into the unsteady and turbulent regimes where the physics is not fully understood and appropriate models for turbulence are not yet established. In the present study the Boussinesq approximation is being used, but the theoretical background and some preliminary results have been obtained [1] for flows with variable properties.

NUMERICAL METHOD

The governing equations in the primitive variables formulation (u,v,T,p) are discretised using finite differences and an ADI scheme. The well established SIMPLE algorithm [2] is used to deal with the continuity constraint and the pressure. Central and hybrid differencing schemes were employed for the discretisation of the corrective terms. The computer code which was developed for the present study was extensively tested for $Ra \lesssim 10^6$ and the results compared well with the benchmark solutions of de Vahl Davis [3]. A more complete description of the computer program may be found in [4].

(a) High Ra Laminar Regime

An air-filled square two-dimensional cavity has been studied. Accurate solutions were obtained from $Ra=10^6$ (Rayleigh number) up to the beginning of the unsteady regime. Central differencing has been used for all laminar calculations, at the highest Ra a uniform 200 x 200 grid was employed. The isotherms and streamlines for $Ra=10^8$ are presented in Fig 1. The streamlines indicate very thin boundary layers are established adjacent to the thermally active walls and separations occur at the top right hand and bottom left hand corners. The core region is stagnant and highly stratified, the stratification being of the order $S = \frac{\partial T}{\partial y} = \frac{\Delta T}{H}$ at the cavity center. The onset of unsteady flow was numerically determined to begin at a critical Rayleigh number of $Ra_c = 2.2 \times 10^8$. These results are in accord with the few existing studies [eg. 5,6]. More details on accurate numerical solutions in the range $10^6 < Ra \lesssim Ra_c$ may be found in [7]. The Ra at which the unsteady laminar flow becomes turbulent is not known but it has been assumed that for $Ra > 10^9$ the flow is turburlent.

b) **Turbulent Regime**

A number of turbulence models ranging from mixing length to a differential Reynolds stress/heat flux model are being investigated. Of primary interest are the effects on the numerical predictions of choice of model, level of model complexity, boundary conditions and variable properties. A previous stage of the research, in which the influence of boundary conditions was investigated was presented at an earlier Natural Convection Workshop and elsewhere [8,9]. The derivation of a Quasi-isotropic stress/heat flux model which incorporates variable properties has also been published. [1]. Also given in [1] were preliminary calculations for an air-filled square cavity at $Ra=10^{10}$. A uniform grid and artificial "forced flow" type boundary conditions for the mean and turbulence quantities were used and consequently the results failed to accurately predict the expected thin boundary layers.

Currently the effects of boundary conditions, model complexity and grid distribution are being investigated. To this end a number of different turbulence models have been coded in and the numerical method has been extended to include non-uniform grid distributions and the implementation of exact Poisson solvers for the pressure correction equation. The resulting computer program is now able to adequately resolve the thin boundary layer and is at least ten times more efficient than its predecessor.

Despite these improvements, numerical predictions for vertical Rayleigh numbers of the order $Ra=10^{10}$ have proved difficult to obtain and are highly grid and model dependent. All computations have been performed for an air-filled cavity of aspect ratio 5 for which experimental data is available [10]. Sample results using a simple mixing length model with two different length scales are presented in Fig 2. The streamlines indicate that significantly different predictions for the horizontal cross-flow were obtained. The maximum vertical velocity at the cavity mid-height (not shown) is predicted adequately although the boundary layer is thinner than has been found experimentally [10]. In contrast, the standard $k-\varepsilon$ model with homegeneous boundary conditions predicts near zero values for the turbulent quantities in all regions of the cavity.

REFERENCES

[1] Naot, D and Reizes, J.A. 1989 Redistribution of Ideal Gas Turbulence in Natural Convection Systems, Israel J. Tech. Vol. 25, pp. 55-72.

[2] Patankar, S.V. 1980 Numerical Heat Transfer & Fluid Flow (Hemisphere).

[3] de Vahl Davis, G. 1983 Natural Convection in a Square Cavity: A Benchmark Numerical Solution, Int.J.Num. Meth.Fluids, Vol.3, pp. 249-264.

[4] Kelson, N.A. 1990 A Computer Code for Enclosed Natural Convection in the Boundary Layer Regime, Univ.NSW, School of Mech. and Manufacturing Eng. Report 1990/FMT/2.

[5] Le Quere (1987) dEtat, Univ. of Poitiers.

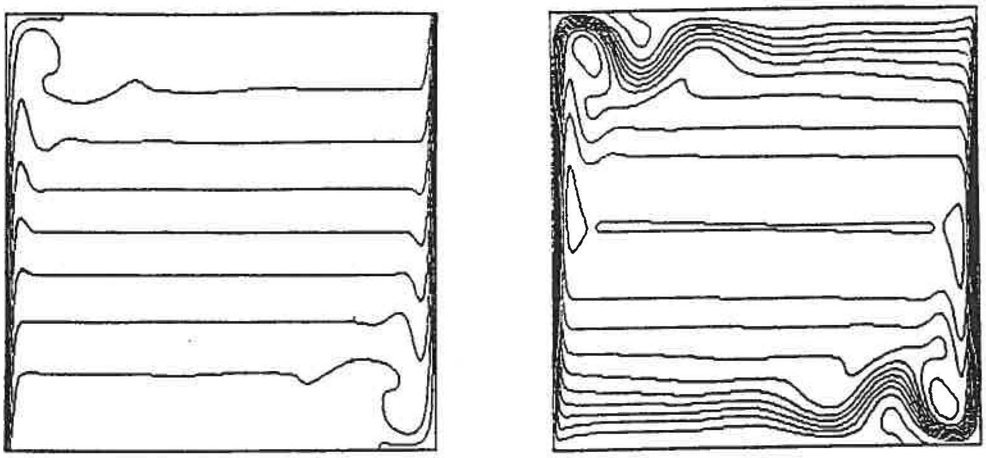
[6] Paolucci, S. and Chenoweth, D.R. 1989 Transition to Chaos in a Differentially Heated Vertical Cavity, J. Fluid Mech., Vol. 201, pp. 379-410.

[7] Kelson, N.A. 1990 The Laminar Boundary Layer Regime Natural Convection of Air in a Square Cavity, Univ. NSW, School of Mech. and Manufacturing Eng. Report /1990/FMT/3.

[8] Reizes, J.A. Behnia, M., de Vahl Davis, G. and Leonardi, E. 1987 Turbulent Natural Convection in a Rectangular Cavity, in Second Australian Natural Convection Workshop Abstracts, Univ. NSW, School of Mech. and Manufacturing Eng. Report /1987/FMT/8, pp.33-40.

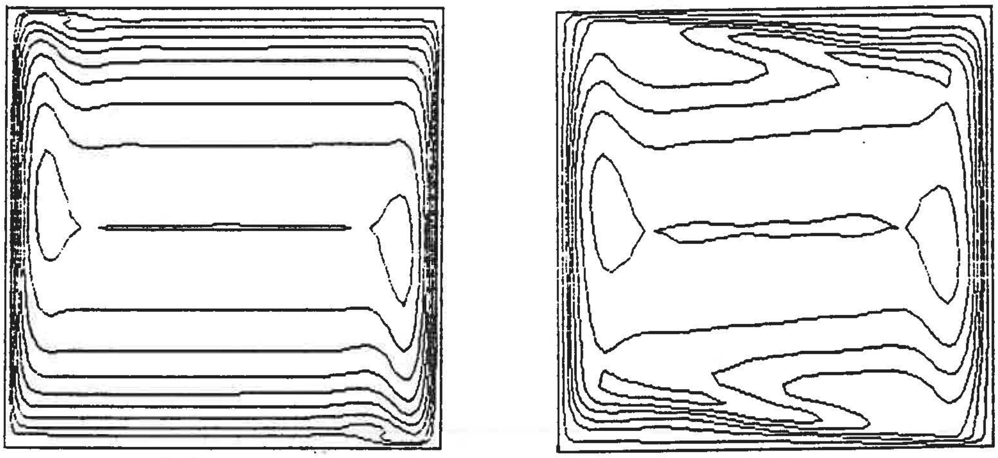
[9] Behnia, M., Cooper, R.K., de Vahl Davis, G., Naot, D., Leonardi, E. and Wolfstein, M. 1988 Turbulent Natural Convection in a Rectangular Cavity, International Symposium on Computational Fluid Dynamics, ISCFD, Sydney, de Vahl Davis, G. and Fletcher, C.A.J. (eds) (North-Holland) Amsterdam, pp. 118-130.

[10] Cheesewright, R., King, K.J. and Ziai, S. 1986 Experimental Data for the Validation of Computer Codes for the Prediction of Two-Dimensional Buoyant Cavity Flows, in, Significant Questions in Buoyancy Affected Cavity Flows, ASME HTD Vol. 60, pp. 75-86.



(a) (b)

Figure 1. $Ra=10^8$: (a) isotherms; (b) streamlines.



(a) (b)

Figure 2. Streamlines at $Ra=10^{10}$ (mixing length model);

(a) length scale of Buleev; (b) length scale based on nearest wall distance.