# MODEL FOR EFFECT OF PLUMES IN TURBULENT FREE CONVECTION BOUNDARY LAYERS

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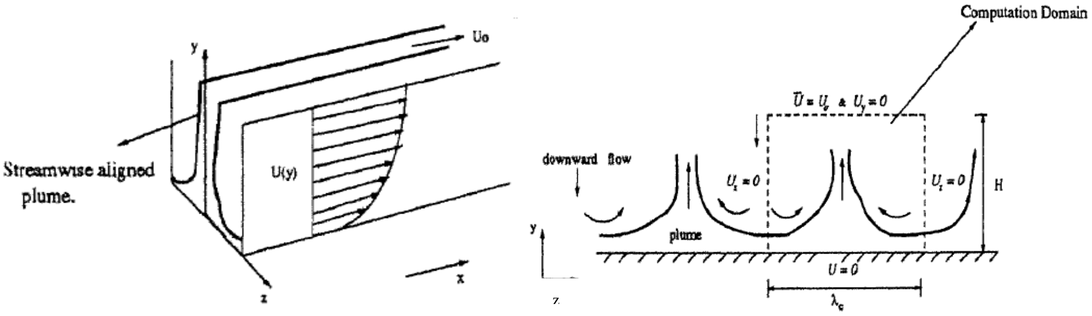
*Summary* Turbulent mixed convection is a complicated flow where the buoyancy and shear forces compete with each other in affecting the flow dynamics. The near wall flow in turbulent free convection over horizontal surfaces, including in R-B convection is dominated by the line plumes. We extend the free convection model of Theerthan and Arakeri [1] to include a free stream flow. Using this model, we determine the profiles of streamwise velocity, Reynolds shear stress and RMS of the fluctuations of the three components of velocity.

## FREE CONVECTION MODEL [1]

Line plumes are the main mechanism of heat transfer near the wall in turbulent Rayleigh Benard (R-B) convection. The near-wall flow may be modelled as a periodic array of 2-d line plumes (Theerthan & Arakeri). Numerical simulation using SIMPLEC algorithm for a 2-d grid of dimension 41x241 is done for one period of the periodic array of plumes. The computation is done in the y-z plane and the length of the domain in the *z* direction is $\lambda_c$ (critical plume spacing), and the height in the y direction is H. The bottom wall temperature is $T_w$.




The above model is extended to include a free stream flow with velocity $U_0$ [2]. This imposed flow could represent free stream flow over a heated plate in a wind tunnel (mixed convection problem) or the large scale wind in R-B convection. There has been a lot of debate on the nature of the boundary layer in R-B convection at high Ra, and the role of plumes in such boundary layers, Xia et al. [3].

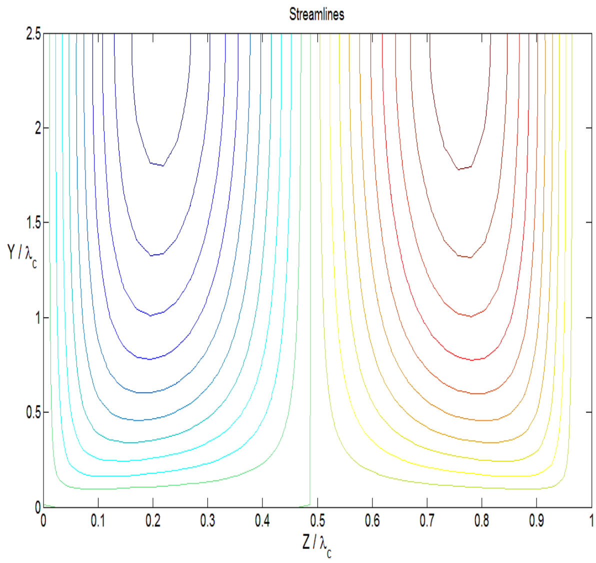



Fig.1. Streamlines in y-z plane

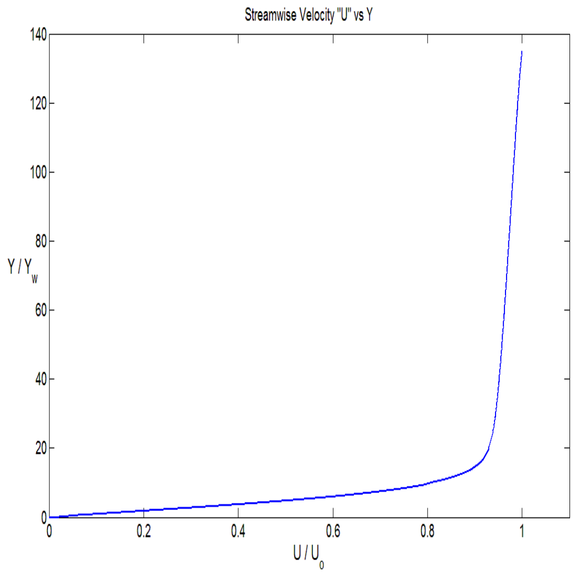



Fig.2. Profile of mean velocity in streamwise direction near the wall

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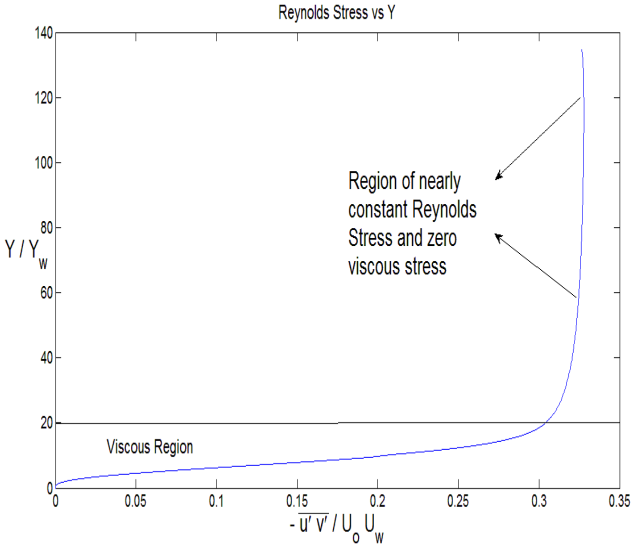


Fig.3. Reynolds stress vs. vertical distance

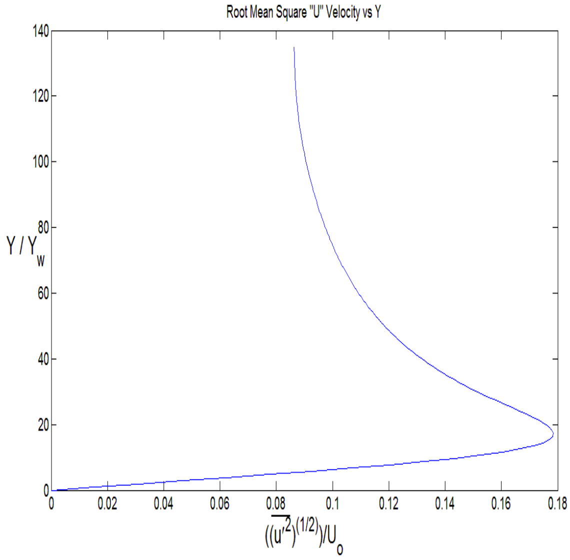


Fig.4. RMS of U vs. vertical distance

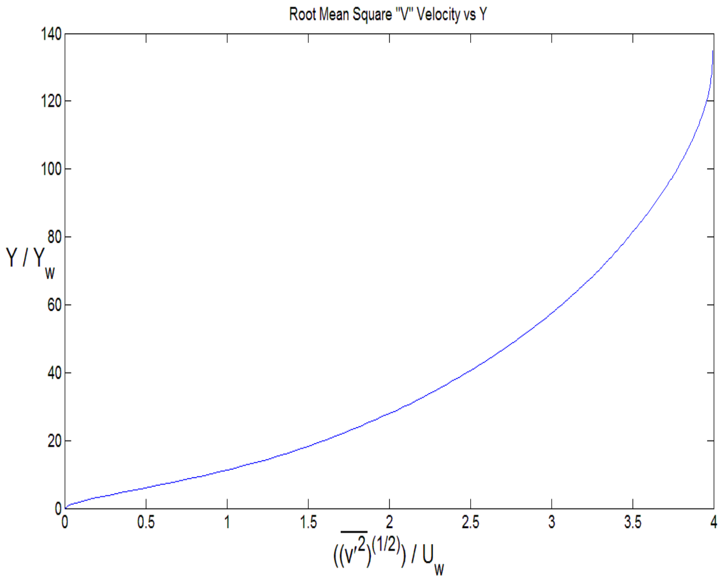


Fig.5. RMS of V vs. vertical distance

The model predicts the near wall profiles of mean velocity and the RMS of the turbulent fluctuations of velocity and temperature. Figure 1 shows the streamlines associated with the plume in one cell. Figure 2 shows the mean velocity in the stream direction; the distance normal to the wall is scaled, $Y_w$, the near-wall scale proposed by Theerthan and Arakeri [1]. The Reynolds stress plot (Figure 3) shows a thin region which is affected by viscosity while in the rest of the region the Reynolds stress keeps a nearly constant value. The profile of the rms of the streamwise velocity fluctuations (figure 4) and the profile of the vertical velocity fluctuations (figure 5) show the combined effect of shear and buoyancy in turbulence production in such boundary layers; the near wall velocity scale, $U_w$, (ref 1) has been used to normalise the vertical velocity fluctuations. In summary, we have presented a model for the boundary layer in turbulent free convection flows which includes the effect of plumes and the free stream flow.

## References

[1] S. A. Theerthan & Jaywant H. Arakeri, A model for near-wall dynamics in turbulent Rayleigh-Benard convection, *J. Fluid Mech* **373**:221-254, 1998.
[2] D.S.Ramesh Chandra, Turbulent Mixed Convection, M.Sc Thesis: *Indian Institute of Science*, 2000.
[3] Chao Sun, Yin-Har Cheung & Ke-Qing Xia, Experimental studies of the viscous boundary layer properties in turbulent Rayleigh-Benard convection, *J.Fluid Mech* **605**:79-113, 2008.