SCALE ANALYSIS AND ASYMPTOTIC SOLUTION FOR NATURAL CONVECTION OVER A HEATED FLAT PLATE AT HIGH PRANDTL NUMBERS

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Abstract. This study presents a free convection flow over a heated flat plate using Bejan's method of scale analysis for balancing forces. For Newtonian fluids of large Prandtl numbers, two different layers which are the thermal and velocity boundary layers exist. The thermal boundary layer is thinner than the velocity boundary layer. The method of matched asymptotic expansion is used to obtain the velocity and temperature within the two layers and these quantities are then matched at the interface. A 5–5 matching is used to obtain both inner and outer solutions for velocity and temperature. A natural small parameter in this problem is the inverse of the square root of the Prandtl number multiplying the highest derivative. In the Bejan formulation for large Prandtl number flows, the two dimensionless quantities that emerge are the Rayleigh and Prandtl numbers as opposed to the Grashof and Prandtl numbers obtained in previous works. The results of velocities, temperature, shear stress and Nusselt number presented in this study are for fluids that have Prandtl numbers ranging 10 to 100,000. The Nusselt number predicted as Prandtl number goes to infinity, approaches the same asymptote as in previous works, while there's about 30% difference in the skin friction predicted when the differences in scaling used are not taken into consideration.

Key words: Large Prandtl number, Scale analysis, Asymptotic expansion, Boundary layer, Free convection.