

## Numerical investigation of the mixed convection flow over a non-isothermal horizontal plate with zero net heat supply

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The steady laminar mixed convection flow over a horizontal plate and the horizontal wake far downstream are studied numerically. The leading edge of the plate is heated while the rest of the plate is cooled, such that the total heat supply is zero. The structure of such flows is of practical interest, e.g., for boundary layer control<sup>1</sup>. In the case of zero net heat supply at the plate, the flow (shown in Figure 1) is substantially different than for a non-zero net heat supply<sup>2,3</sup> and no analytical solutions are currently available. This may present a complication for formulating appropriate outflow boundary conditions in CFD applications<sup>4</sup>. To mitigate such complications, the flow is guided by walls of a horizontal channel and a hydrostatic pressure profile is prescribed along the outflow boundary<sup>5</sup>.

The focus of this work is to study the structure of the wake behind the plate, depending on the parameters of the flow. The spreading rate and the decay rates of temperature and velocity perturbations, respectively, in the far wake are determined, and a self-similar structure of the far wake is revealed. These results can be used as a guidance for finding analytical solutions of the flow.

The temperature perturbation decays along the wake faster than in the case of non-zero net heat supply<sup>3</sup>. Furthermore, the decay rate and the structure of the far wake depend on the relative importance of natural convection, quantified by the Richardson number ( $Ri$ ). For pure forced convection flow ( $Ri = 0$ ), the temperature perturbation is symmetric about the plane of the plate and decays with the distance from the plate ( $X$ ) as  $X^{3/2}$ . In the case of a mixed convection flow ( $Ri \neq 0$ ), the far wake stratifies into a hot layer in the upper part and a cold layer in the lower part. Then, the antisymmetric temperature perturbation is found to decay as  $X^{-1}$ . The width of the wake and the velocity defect are  $\propto X^{1/2}$  and  $X^{-1/2}$ , respectively. Within the conditions considered, the aforementioned exponents are found to be universal constants independent of the Prandtl number. It is remarkable that the decay rates of the temperature perturbation are in contrast to the classical solution for a plane laminar wake, while the spreading rate and the decay rate of velocity perturbation, respectively, comply with the classical solution.

Except for small Prandtl number, the temperature perturbation, combined with the velocity defect, leads to a hydrostatic pressure jump across the near wake. This pressure jump is compensated by a perturbation of the outer potential flow around the plate<sup>2</sup>. As the hydrostatic pressure jump decays along the wake, the perturbation of the outer flow also decays with increasing distance from the plate. In the limit of a vanishing Prandtl number, the perturbation of the flow by buoyancy occurs mainly inside the inviscid thermal boundary layers, while the outer flow remains almost unperturbed. In either case, the perturbation of the flow leads to a positive lift force acting on the plate.

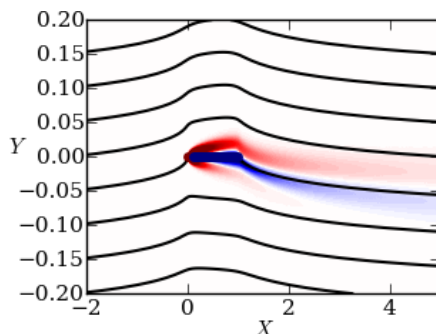


Figure 1: Streamlines (black) and temperature perturbation (color) of the flow over a cold plate with a hot leading edge.

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<sup>1</sup> Aslani et al., *AIAA J.* **61** 2948 – 2969 (2023)

<sup>2</sup> Schneider, *Proc. 3rd European Thermal Sci. Conf.*, 195 – 198 (2000)

<sup>3</sup> Schneider, Bábtor, *Eur. J. Mech. B Fluids* (2025) [in press]. DOI: 10.1016/j.euromechflu.2024.12.007

<sup>4</sup> Bábtor et al., *J. Phys. Conf. Series* **2766** 012061 (2024)

<sup>5</sup> Bábtor, *Proc. Appl. Math. Mech.* **23** e202300030 (2023)