3D FLOW TRANSITION BEHIND A HEATED CYLINDER

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Summary: In the present study the 3D transition behind a **heated** cylinder is investigated at low Reynolds numbers: $Re = \mathcal{O}(100)$. For a Richardson number $Ri \geq 1.0$, the 3D transition manifests itself in the form of escaping thermal plumes in the far wake. From a numerical simulation at $Re = 85$ and $Ri = 1.0$, it is observed that the formation of the plumes is associated with pairs of counter-rotating vortices occurring close behind the cylinder.

INTRODUCTION

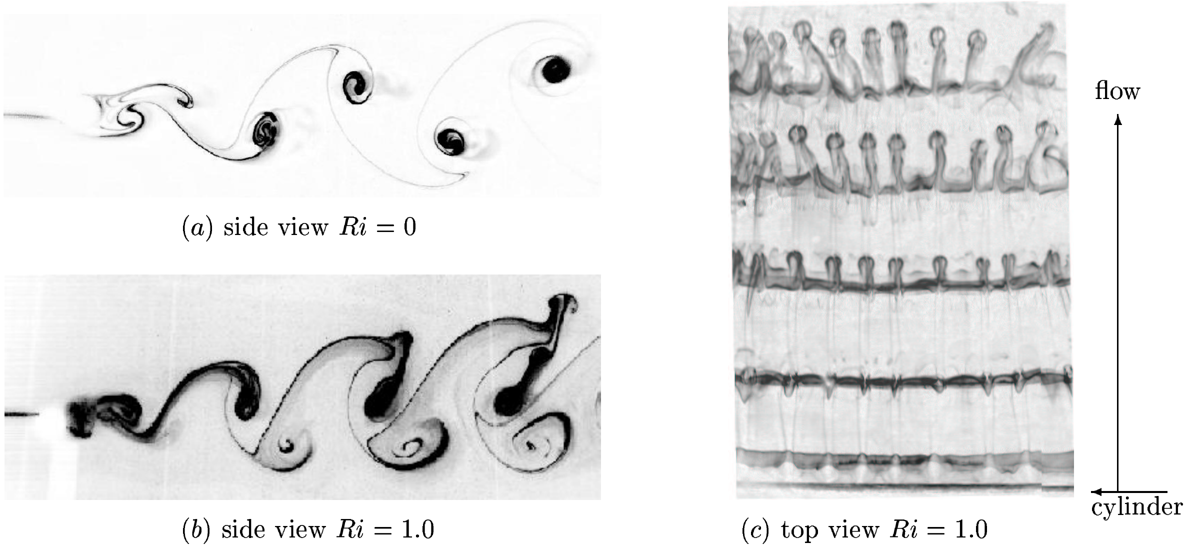
Over the last ten years, a lot of attention has been paid to the 3D transition of the wake flow behind a cylinder. Experimental, numerical and theoretical studies significantly contributed to the understanding of the dynamics. From a fundamental point of view, studies on the instability mechanisms resulting in the formation of 3D vortical structures, can contribute to a better understanding of laminar-turbulent transition and may lead to ways to actively control the features of the flow.

For the unheated case, the wake flow is characterized by the Reynolds number. For a Reynolds number around $180 - 190$, a 3D transition occurs with a spanwise wavelength of 3-4 cylinder diameters. For a Reynolds number around $230 - 260$, 3D structures occur with a spanwise wavelength of 1 cylinder diameter.

The effect of a heat input on the behavior of the shed coherent structures received almost no attention until the recent studies by Kieft *et al.* [1]. He investigated the wake structure behind a heated horizontal cylinder in cross-flow with water as the working fluid. For low Reynolds numbers, Kieft *et al.* [1] found that by heating the cylinder, the vortices in the upper and lower rows acquire different strengths due to baroclinic vorticity production. This strength difference increases for increasing Richardson numbers. It was observed that for small Richardson numbers the shed vortices move slightly downwards. A more extensive literature review and a summary of earlier results on the wake behavior behind a heated cylinder of our research group is given in van Steenhoven and Rindt [2].

THERMAL PLUMES IN THE FAR WAKE

In the present study the 3D transition of the wake flow behind a **heated** cylinder is investigated at a Reynolds number $Re = \mathcal{O}(100)$. In Figure 1 (a), for $Ri = 0$, the wake flow manifests itself as the von Kármán vortex street. If one increases the heat input, for $Ri \geq 1$ a 3D transition manifests itself in the form of escaping thermal plumes [3], see Figure 1 (b). The spanwise distance of the plumes is around 2 cylinder diameters, as shown in Figure 1 (c).



(a) side view $Ri = 0$

(b) side view $Ri = 1.0$

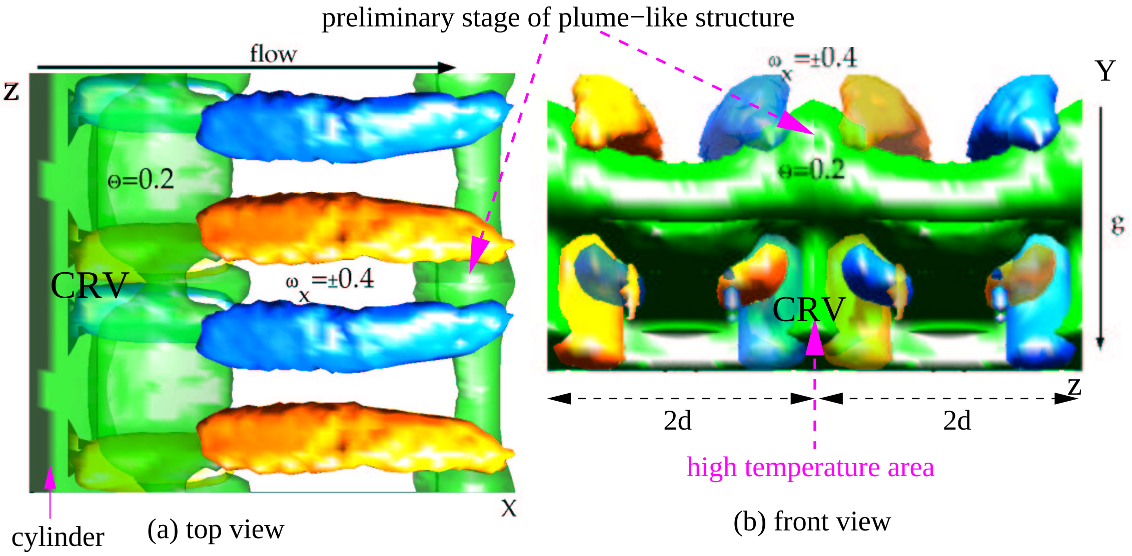
(c) top view $Ri = 1.0$

Figure 1: Visualization of the wake flow at $Re = 117$ and $Ri = 0$, $Ri = 1$.

COUNTER-ROTATING VORTICES IN THE NEAR WAKE

To understand the flow structures observed from the experiments, Spectral Element calculations are carried out for $Re = 85$ and $Ri = 1.0$. Numerical simulations provide more detailed insight into the occurrence of the 3D transition.

In Figure 2, iso-vorticity surface $\omega_x = \pm 0.4$ (vorticity component in streamwise direction) and iso-temperature surface $\Theta = 0.2$ are presented. In Figure 2 (a), the flow is from left to right. It is observed that pairs of counter-rotating vortices (CRV) appear close behind the cylinder. The CRV have a spanwise distance of around 2 cylinder diameters. In Figure 2 (b), the flow is pointing towards the observer. It is seen that the fluid at the center region of the CRV has a high temperature. Due to the non-uniform temperature distribution in spanwise direction, streamwise vorticity ω_x is generated due to the baroclinic vorticity torque $-\partial_z \Theta \times \mathbf{g}$ (Ren *et al.* [4]).



(a) top view

(b) front view

Figure 2: Snap-shot of calculated iso-vorticity $\omega_x = \pm 0.4$ surfaces and iso-temperature $\Theta = 0.2$ surface at $Ri = 1.0$, $Re = 85$. The spanwise distance of the CRV is around 2d, d is the cylinder diameters.

Furthermore, we observe the preliminary stage of plume-like structures in the upper vortices, as indicated in Figure 2. From the numerical calculations, the formation of the plume-like structures is associated with the counter-rotating vortices 'curling' around the upper voritces.

AIM AND PLAN

The evolution of the counter-rotating vortices and the formation of the escaping plumes will be studied as function of the Richardson number. From a fundamental point of view, a detailed study on the origin of the counter-rotating vortices in the near wake and the thermal plumes in the far wake will contribute to a better understanding of 3D transition behind heated bluff bodies. This will be the topic of the present paper.

References

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