Forced reattachment in separated flows: a variational approach to recirculation length reduction

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Sensitivity analysis is used to design an open-loop control for separated flows. The length of the recirculation region l_c is expressed as a cost functional, and its sensitivity to actuation is derived analytically. This analysis allows to identify regions where steady actuation in the volume and at the wall are most efficient to decrease/increase the recirculation length. It holds both for separation behind bluff bodies and for wall-bounded separation.

The method is illustrated with two configurations: the flow past a circular cylinder, and the boundary layer flow over a wall-mounted bump. In the cylinder flow, a decrease of l_c is obtained with normal blowing in the downstream region of the cylinder wall, or using small cylinders as control devices close to the shear layer. Global linear stability analysis reveals that these controls restabilize the flow in a range of supercritical Reynolds numbers.

In the bump flow, wall suction at the bump summit has a strong reducing effect on l_c. It also proves very efficient in dampening noise amplification, as shown by the calculation of linear optimal harmonic response for Reynolds numbers below the onset of 2D instability.

These results show that the recirculation length may be used as a single macroscopic surrogate for eigenvalues (in oscillator flows) and optimal gain (in amplifier flows) when designing open-loop control.

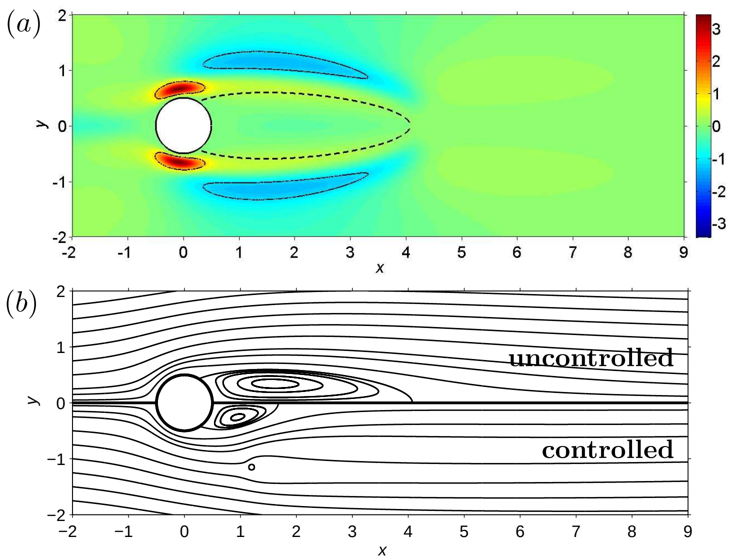

Figure 1: (a) Variation of the steady-state recirculation length $\delta l_c(x_c, y_c)$ at $Re = 60$ as predicted by sensitivity analysis when a small control cylinder is located in (x_c, y_c). Solid contours show $\delta l_c = \pm 1.1$. The dashed line is the separatrix. (b) Effect of two small control cylinders (ten times smaller than the main cylinder, $d = D/10$) located symmetrically in $(x_c, y_c) = (1.2, \pm 1.15)$: streamlines of the uncontrolled (upper half) and controlled (lower half) steady-state flow, obtained with nonlinear Navier–Stokes calculations.