ACFD 2018 Project 4 discussion

Task 1

See reference solutions for the contour plots and the typical values of period and amplitude of oscillation for the three cases with circular and elliptic cylinders. The simulation of the oscillation is somewhat sensitive to the setup of time step size and number of iterations per step. The reference solutions represent the range of the most robust results. In particular, the amplitude of oscillation is the highest for the case with an ellipse elongated in y-direction, followed by the case with a circular cylinder. The case with an ellipse elongated in x-direction produces a more muted oscillation. This behavior is consistent with the video we showed in class. The period of oscillation is the longest for the case with an ellipse elongated in y-direction, and shortest for the case with an ellipse elongated in x-direction.

Task 2

See reference solutions for the contour plots of velocity, and the typical values of lift and drag force as a function of tilt angle. The drag force increases monotonically with the tilt angle. This is not surprising given the significant increase in the cross-sectional area with an increasing angle. The behavior of the lift force is more subtle. The most robust results (produced with sufficient numbers of iterations, etc.) have the lift force peaking at $\theta = 30°$, then decreasing with a further increase of θ. (See reference solution #1 for demonstrations of how the lift or drag depends on the number of iterations.) The case of $\theta = 45°$ resembles the situation of “stalling”.

Task 3

See reference solutions for the contour plots of pressure and velocity, and the reports of the drag forces. As is typical for a flow over an obstacle, we see high pressure on the upstream side of the building and a “wind shadow” of low velocity (even reverse flow) on the downstream side of the building. There is also notable acceleration over the rooftop above the leading edge (facing the incoming flow) of the building.

The total drag (that the fluid exerts on the building) is higher for the case in Task 3(b). The reference solutions represent the range of most robust results for the drag and its two components. In both systems in Task 3(a) and 3(b), the contribution to the total drag overwhelmingly comes from the pressure term.

We will attempt to provide a heuristic explanation of why the pressure component of the drag completely overwhelms the viscous component:

Recall the discussion on the overall balance in momentum equation (i.e., Navier-Stokes equation). For a steady flow (or a general flow after some time averaging), we have

0 = (inertial term) + (pressure gradient force) + (viscous term) .

For an incompressible flow, PGF balances with the winner of the competition between inertial and viscous terms. As Reynolds number represents the ratio of (inertial term)/(viscous term), the primary balance is (inertial term) $\approx$ PGF for a high Reynolds number flow, and PGF $\approx$ (viscous term) for a low Reynolds number flow. Also recall that the “pressure” and “viscous” components of the drag come from the integrals of the PGF and viscous terms, respectively. At high Reynolds number (as is the case for the systems in Task 3), since PGF ≈ (inertial term) >> (viscous term), we have PGF >> (viscous term), thus the pressure component overwhelms viscous component of the drag. Note that even at very low Reynolds number we still have PGF ≈ (viscous term), and the pressure component would still be comparable to the viscous component.