Lift estimation by the velocity circulation around a body from PIV measurements

P. BOT[a], L. MICHEL[a]

Arts et Métiers ParisTech / IRENAV Ecole Navale
BCRM Brest CC600 29240 Brest Cedex 9
Contact : patrick.bot@ecole-navale.fr
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1 Extended abstract

The estimation of aero or hydrodynamic forces generated by a slender lifting body or a bluff body subjected to a flow is of great interest in many applications in the field of fluid mechanics. Forces are often directly measured thanks to a force balance based on strain gauges. Alternatively, it is possible to estimate fluid forces on a body from measurements of the velocity field around the body. Several studies have addressed this issue with a lot of effort thanks to accurate PIV measurements (Particle Image Velocimetry), with reasonable success, providing the velocity measurements and processing are refined enough as to give an accurate computation of local fluid quantities and their derivatives in the whole field, e.g. [1-3]. In the present work, we show that a very simple analysis of moderate-resolution PIV measurements, based upon the velocity circulation around the body can give a good estimation of the lift force around a body and its evolution in time. Both cases of slender and bluff bodies are investigated.

According to potential flow theory and the Kutta-Joukowski theorem [4], the lift coefficient C_L of a 2D wing section is proportional to the circulation of the velocity vector on a contour around the section: $C_L = \frac{2\,\Gamma}{U_\infty\ c}$, where U_∞ is the upstream velocity, c is the section chord length and $\Gamma = \oint U\,dl$ is the velocity circulation along a closed path around the section.

We performed time-resolved 2D PIV measurements in the mid-span plane around both a NACA0015 wing section and a cylinder in the IRENav hydrodynamic tunnel, simultaneously to force measurements via a strain-gauge hydrodynamic balance, for different values of the flow velocity and, in the case of the wing section, in a large range of angle of attack. For the wing section, the time-averaged lift coefficient from PIV is in good agreement with the force balance before stall, and is under-estimated by around 20% in the stalled regime, as shown on Fig. 1.

Moreover, the time series of the velocity circulation gives interesting information on the dynamics of the flow in the presence of vortex shedding, which is more representative of the global flow behavior than the time series of the velocity at a particular location would be. Figure 2 shows an example of instantaneous velocity field and the lift coefficient time series determined by velocity circulation around the section in the stalled regime where fluctuations are strong.

In the case of the flow around a cylinder, which is dominated by vortex shedding, the instantaneous lift coefficient computed by the velocity circulation from PIV shows strong oscillations around zero, with similar dynamics to the one from the force balance, as shown on Fig. 3. It is not surprising that the fluctuations of this sectional 2D lift are higher than the fluctuations of the lift from the balance, as the latter is global to the whole span of the foil, and integration along the span may well attenuate the fluctuations if the vortex shedding is not perfectly in phase along the span, as is often observed in the wake of a cylinder (see e.g. [5]).

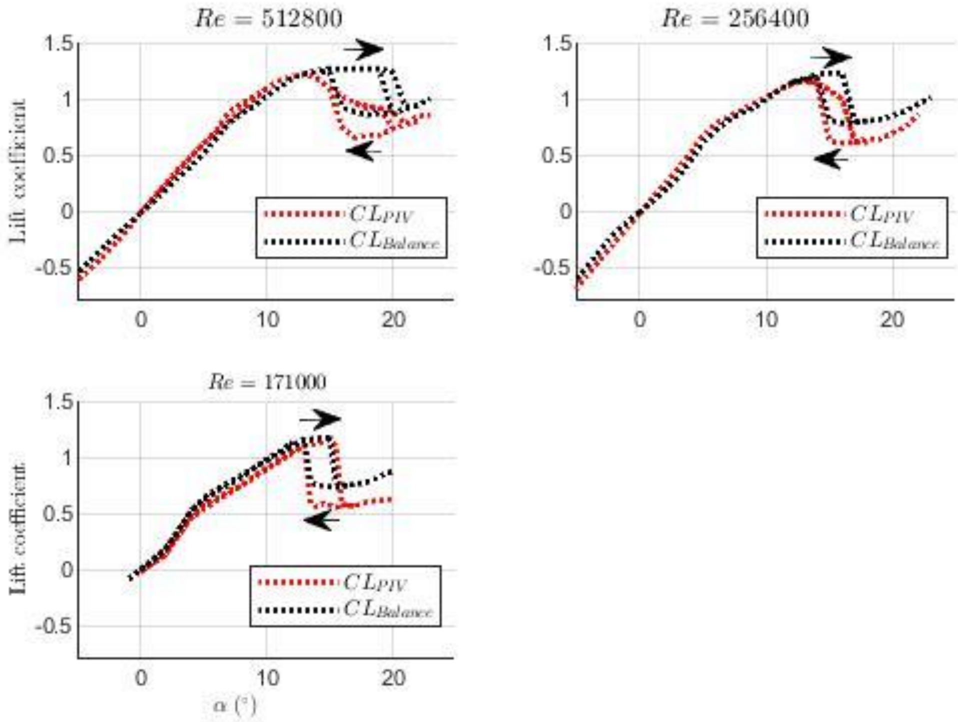

Fig. 1: Lift coefficient versus angle of attack from force balance and circulation from PIV, on a NACA0015 wing section for different Reynolds numbers.

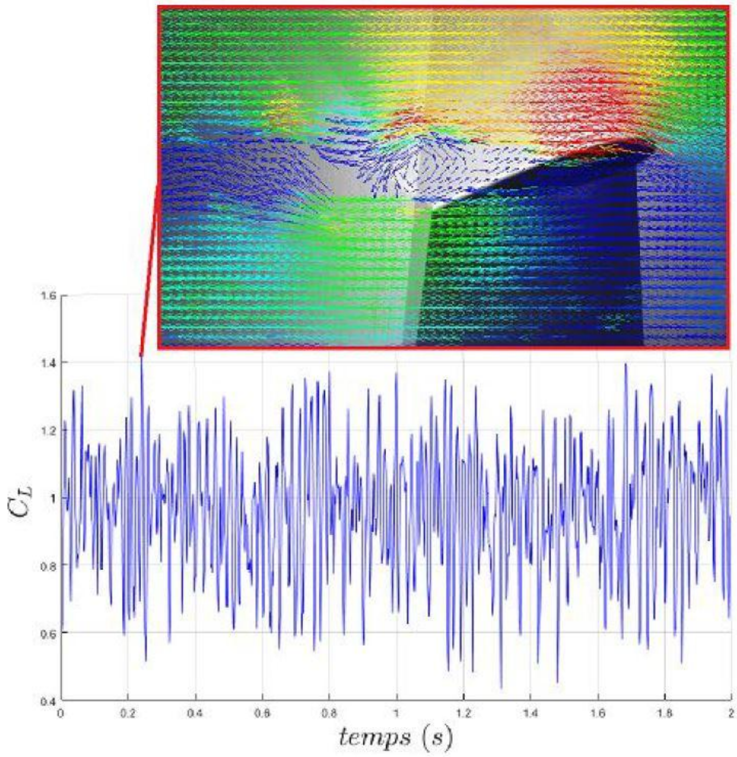

Fig. 2: Snapshot of the velocity field around a NACA0015 wing section at Re=512800 and 17° angle of attack, and time series of the fift coefficient obtained with circulation from PIV.

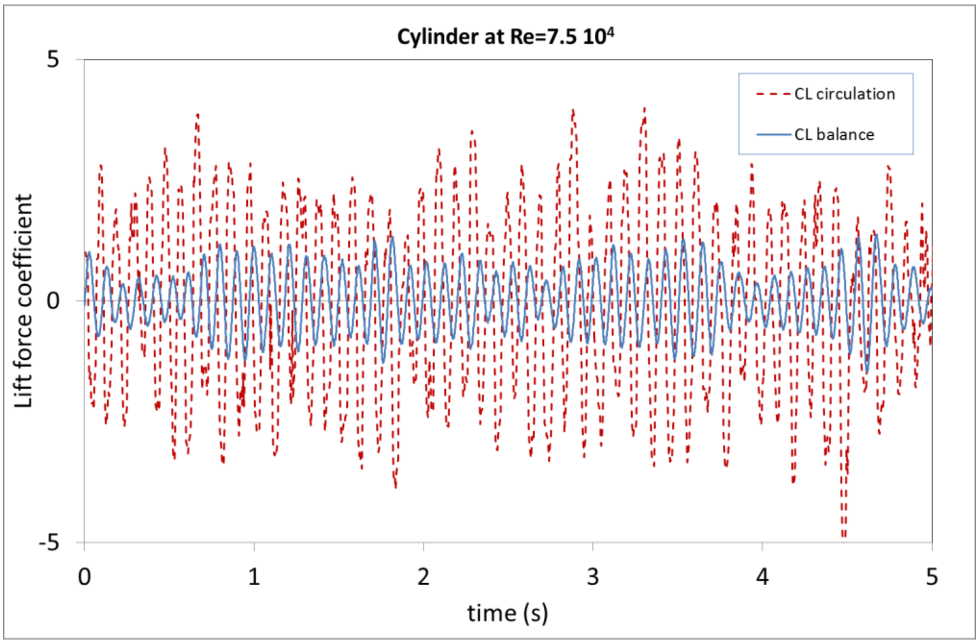

Fig. 3: Time series of the lift coefficient from force balance and circulation from PIV on a cylinder at a Reynolds number of 75000.

References

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