Aerodynamics of a two-dimensional hovering wing in ground effect

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This project aims to investigate ground effect on a two-dimensional wing flapping in a normal hovering mode. The study may provide a useful insight into the aerodynamics of insect flight in close proximity to a surface. While ground effect on a fixed wing has been explored extensively, very few studies have been conducted on ground effect on flapping wing (Gao and Lu, 2008). In this experiment, a generic 2-D elliptic wing was subjected to simple harmonic translational and rotational motions at Reynolds number (based on the root mean square velocity and wing chord length, c) of 1000. Three rotation amplitudes (α = 30, 45 and 60°) were considered for a range of ground clearance (defined as the distance between the wing center and ground surface) D from 1c to 5c. DPIV and force measurements were conducted to capture flow structures and the corresponding force characteristics, respectively.

Fig. 1 shows the cycle-averaged lift and drag coefficients versus the ground clearance for rotation amplitude of 45°. It can be seen from the figure that decreasing ground clearance leads to a reduction in both the lift and drag coefficients until D/c=2.0, before they increase rapidly thereafter. This behavior is in contrast to fixed wing aerodynamics where lift is known to increase monotonically with decreasing ground clearance, but it is consistent with the recent numerical study by Gao and Lu (2008) for a similar wing flapping motion, but at a much lower Reynolds number of 100. The authors divided the force distribution into three broad regimes, which they refer to as “force enhancement”, “force reduction” and “force recovery” as the wing recedes from the ground. Our DPIV measurements show that the initial decrease in the cycle-averaged forces as the wing approaches the ground from afar may be due to a weaker delayed stall. This can be clearly seen from the snapshots of vorticity contours depicted in Fig. 2. Of particular interest is the result at t*=0.3 (t* is the non-dimensional time) where it can be seen that the leading-edge vortex (LEV) finds it more difficult to attach to the leeside of the wing as D/c decreases, indicating a significantly stronger wake capture effect as can be seen in the result of t*=0.0 where the induced velocity is pointing and impinging more towards the wing. This leads to a more favorable wing-wake interaction as described by Lua et al. (2011).

More detailed results, including other rotation amplitudes are presented in the full paper.

References

Gao T, Lu XY (2008) Insect normal hovering flight in ground effect. Phys Fluids 20, 087101


Lua KB, Lim TT, Yeo KS (2011) Effect of wing-wake interaction on aerodynamic force generation on a 2D flapping wing. Exp Fluids 51 (1):177-195

Fig. 1 Cycle-averaged lift and drag coefficients vs ground clearance at rotation amplitude 45°

Fig. 2 Vorticity contours at t*=0.0 and 0.3 for (a) D/c =1.0, (b) D/c =2.0 and (c) D/c =3.5 at rotation amplitude 45°. G indicates ground position. Here, vorticity is normalized by flapping frequency and time by period.