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Numerical simulations of the clap-fling-sweep mechanism of hovering insects

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Fig. 1: Fruit fly.

Summary

The Lighthill-Weis-Fogh clap-fling-sweep mechanism is a movement used by some insects (Fig. 1) to improve their flight performance. As first suggested by Lighthill (1973) [5], this mechanism allows large circulations around the wings to be established immediately as they start to move. Initially, the wings are clapped. Then they fling open like a book, and a non-zero circulation is established around each of them. Thus one wing can be considered as the starting vortex for the other. Then they sweep apart, carrying these bound vortices and generating lift. Since the insect wings have relatively low aspect ratio and rotate, 3d effects are important, such as spanwise flow and stabilization of the leading edge vortices (Maxworthy, 2007) [6]. To explore these effects, we perform direct numerical simulations of flapping wings, using a pseudo-spectral method with volume penalization. Comparing 2d and 3d simulations for the same setup clarifies the role of the three-dimensionality of the wake. Our results show that the 2d approximation describes very well the flow during fling, when the wings are near, but 3d effects become crucial when the wings move far apart.

Results of fully three-dimensional numerical simulations of the clap-fling-sweep mechanism using a Fourier pseudo-spectral method with volume penalization [2] are presented in the following. Figure 2 shows the absolute value of the vorticity at three time instants. At t=1.2, very strong leading-edge vortices result from the air flow into the opening space between the wings. A vortex which reconnects the wing ends forms a horseshoe shape at later times. Another interesting point of investigation is that not all rotating wings produce stable leading-edge vortices.

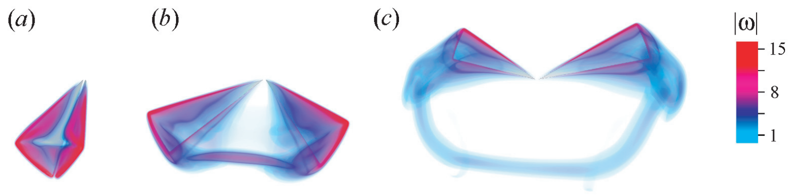

Fig. 2: Vorticity magnitude at time t=1.2 (a), 3.2 (b) and 7.2 (c).

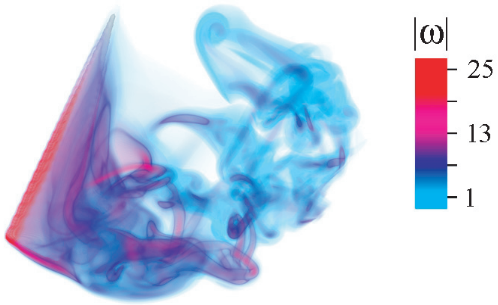

Fig. 3: Vortex shedding from a very elongated wing. Shown is vorticity magnitude.

Figure 3 depicts a wake of a very elongated single wing, $r*/c* = 9$. The wing rotates with a constant speed corresponding to Re=200 at its mid-section $R/2$. The spatial resolution of this simulation is $N^3 = 512^3$.

Further details on the presented material can be found in the following references [2, 3, 4]. Possible extensions of the numerical method for modeling the interaction with thin elastic wings using different fluid-structure coupling schemes will also be presented [1] and will be published in a forthcoming paper.

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