An analysis of maneuverability of insects flight using steady and unsteady flights

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ABSTRACT

In insects' flight, vorticies generated by flapping wing are very important; Such vorticies do not only enhance the lift but affect the dynamic balance of force and moment acting on the insect[1]. In particular, they contribute to the stability and the maneuverability because we often observe that insects show a quick change of flight direction, not gradual change by successive quasi-steady balance. Flight of a butterfly *Parantica sita* has been analyzed by measurements and numerical simulations[2], but such maneuverability has not been analyzed in detail. So far, several two-dimensional models have been studied, and it is shown that bifurcation structures of steady flight can account for not only its mathematical structure but also dynamics of flapping flight using vortex[3,4].

To understand maneuverability of vortex-using flapping flight, we consider a two-dimensional model. This model consists of a single flapping wing and all the mass is concentrated at the centre of oscillation. We solved numerically the coupled system between the centroidal motion of the model and the fluid motion caused by the flapping. For the pitching motion, we assume an ideal control to fix the pitching angle constant. Using appropriate parameters based on the measurements of *Parantica sita*, this model attains steady flights without any controls.

A bifurcation diagram of the steady states for a kinematic parameter consists of two branches. One branch represents a forward flight with a sharp transition where the wake pattern changes qualitatively. The other branch represents a backward flight. Both states are bistable in a parameter range. The critical values for the transition and the end of a backward-flight branch are close to the parameters for *Parantica sita*. Further, an unstable flight is suggested in the bistable region. The unstable flight separates the final states of the flight, which is demonstrated by a simple change of wing motion.

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