Diving of surface-dwelling insects at the capillary scale

Yukun Suna[1], Emily Palmer[2], Christopher Dougherty[1], & Chris Roh[1]
1 Department of Biological and Environmental Engineering, Cornell University, Ithaca, NY 14850, USA
2 Department of Physics, The Cooper Union, New York, NY 10003, USA

Whirligig beetles (Gyrinidae) are the fastest-swimming surface-dwelling insects. This one-centimeter-long beetle live and socialize on the water surface. They can reach a peak acceleration of 10g and a top velocity of 100 body lengths per second. They are also well-known for their agile maneuverability for prey capture and threat avoidance. To live and socialize on water surface, the morphology of the whirligigs has been highly adapted to their locomotion on water surface. They have evolved flat oar-like mid- and hind-legs, the latter of which plays a more important role in fast swimming. Our previous work has suggested that they use lift produced on the legs as a propulsion mechanism for the fast swimming on the free surface.

In addition to the fast-swimming capability, whirligig beetles also display exceptional performance for threat avoidance of predators approaching the free surface. When stimulated while swimming on the free surface, they rapidly transition from free surface to underwater swimming by diving into water. In this work, we performed *in vivo* experiments to uncover the mechanism for this locomotory modal transition at the capillary scale. Our analysis shows that they dynamically change the shape of the rear abdomen, which readily was bent downwards when the whirligig was initiating diving. We hypothesize that the torque generated by the added drag on the abdomen rotates the whirligig's body in a direction favorable to its diving.

Additionally, we present flow visualization and force measurement results around a simplified mechanical model diving from the free surface. We also propose a mechanistic model for the torque balance with surface tension inevitably posed to the problem at small scales. By comparing the theoretical model with mechanical experiments, we predict the relation between swimming speed and body shape required for successful diving at capillary scale.

Email address for correspondence: *ys655@cornell.edu*