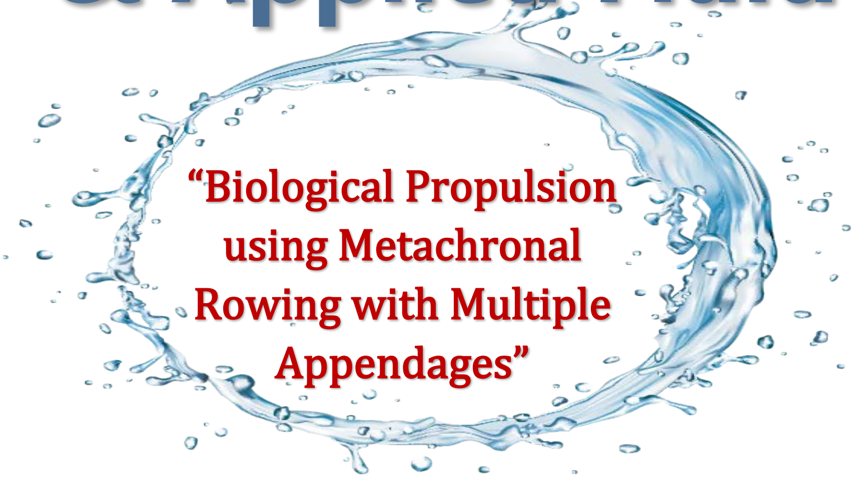
Center for Environmental & Applied Fluid Mechanics



“Biological Propulsion using Metachronal Rowing with Multiple Appendages”

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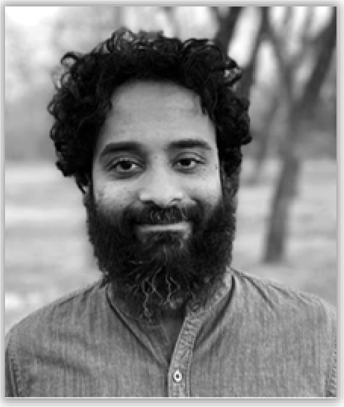
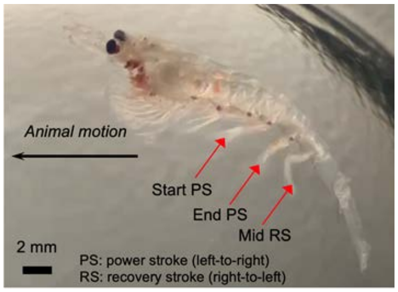


Abstract: Metachronal rowing is a widespread swimming strategy used by many aquatic invertebrates of sizes ranging from 0.01 mm to 100 mm. A series of closely spaced appendages (hereafter referred as paddles) are rhythmically oscillated in sequence starting from the tail to the head, creating a traveling wave that moves along the body in the same direction as animal motion. While many studies have investigated the kinematics, hydrodynamics, and swimming performance of biological metachronal swimmers, the differences in morphology and behaviors make it difficult to synthesize the physical mechanisms underlying this successful locomotion strategy. By using experimental and computational modeling approaches, we are the first to systematically investigate the physical and kinematic parameters that affect metachronal rowing performance. Using measurements on a fixed robotic model, we found that the counter-rotating tip vortices generated by adjacent paddles merge to form a horizontally angled wake jet, the angular orientation of which can be controlled by changing the phase lag (PL) between adjacent paddles. Vertical momentum transfer was observed with increasing Reynolds number (*Re*) based on paddle length, which can aid in weight support of larger, negatively buoyant crustaceans. Using a self-propelling robot, we found that both the swimming speed and thrust generation were highest for PL in the range of 15-25% that is observed in freely-swimming Antarctic krill. The effect of PL was greatest for closely spaced paddles (ratio of inter-paddle spacing to paddle length < 1), as interactions between the individual paddle-tip vortices are limited for larger spacing. Increasing the number of paddles results in an increase in swimming speed but decreases per-paddle swimming speed and circulation in the thrust-generating paddle-tip vortices. While using a larger number of paddles can be used to augment swimming speed and agility, it is accompanied by lower efficiency due to destructive interactions between the pressure fields of adjacent paddles. Our studies cover 6 orders of magnitude of *Re* (0.1 to 10,000) and show that Strouhal number is nearly constant for *Re* ranging from 50 to 50,000. These studies have been used to develop remotely operated bioinspired underwater vehicles.



Spring 2025 CEAFM Seminar Series

February 18, 2025 ✦ 3:00 PM ✦ Hodson 210