ABSTRACT

Fish-like propulsion has attracted significant attention for applications involving navigation in confined and complex flow environments, such as biomedical microrobots, pipeline inspection systems, and autonomous underwater vehicles operating in shallow or wall-bounded domains. In many such applications, swimming occurs in narrow channels where the flow is pressure-driven and strongly influenced by nearby boundaries. The hydrodynamics of fish-like swimming under these conditions differ fundamentally from those in unbounded or quiescent flows. The present work investigates the hydrodynamics of fish-like hydrofoils swimming in confined environments. A high-fidelity sharp-interface immersed boundary method is employed to perform two-dimensional numerical simulations of rigid pitching and flexible undulating hydrofoils. This study systematically examines the influence of wall clearance, Strouhal number, wavelength, and Reynolds number on pressure thrust, viscous drag, power consumption, swimming efficiency, and wake dynamics. Initially, the hydrodynamic performance of a rigid pitching hydrofoil in fully developed plane Poiseuille flow is analysed, revealing non-monotonic variations in thrust, lift and torque due to vortex interaction and wall clearance. Then, the effects of wall proximity on flexible undulating hydrofoils are investigated, demonstrating that moderate confinement enhances pressure thrust efficiency, whereas higher wall proximity increases viscous drag and degrades efficiency relative to freestream swimming. The differences between pitching and undulating kinematics in terms of wake dynamics, thrust enhancement, and power consumption are also discussed. We further explore the swimming behaviour of deformable undulating hydrofoils in narrow channels, including upstream swimming against pressure-driven inflow. The scaling relationships for pressure thrust and viscous drag are proposed as functions of the nondimensional wavelength, the Strouhal number, and the wall clearance. The results provide fundamental insights into the hydrodynamics of confined swimming and offer design guidance for efficient bio-inspired propulsion in wall-bounded, pressure-driven flow environments.

Keywords: Fish Swimming, Autonomous Underwater Vehicle, Wall Effect, Hydrodynamics, Anguilliform, Rigid Hydrofoil, Immersed boundary method.