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Hydrodynamics of Undulating Ribbon-fin and Its Application in Bionic Underwater Robot

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Abstract : The Gymnarchus Niioticus fish(GNF) cruises generally with high efficiency by undulating ribbon-fin propulsion while keeping its body for straight line. The swing amplitude of GNF fins is usually in 60° to 90°, and in normal state the amplitude is close to 90°, only in the control of hovering or swimming at very low speed, the amplitude is smaller (about 60°). It provides inspiration for underwater robot design. In the paper, the unsteady flow of undulating ribbon-fin propulsion is numerical simulated by the dynamic grid technique including spring-based smoothing model and local grid remeshing to adapt to the fin surface significantly deforming, and the swing amplitude of fin ray reaches 850. The numerical simulation method is validated by thrust experiments. The spatial vortex structure and its evolution with phase angle is analyzed. The propulsion mechanism is investigated by comprehensive analysis of the hydrodynamics, vortex structure, and pressure distribution on the fin surface. The numerical results indicates that there are mainly three kinds of vortexes, i.e. streamwise vortex, crescent vortex and toroidal vortex. The intensity of streamwise vortex is the strongest among all kinds of vortexes. Streamwise vortexes and crescent vortexes all alternately distribute on the two sides of mid-sagittal plane. Inside the crescent vortexes is high-speed flow, while outside is low-speed flow. The crescent vortexes mainly induce high-speed axial jet, which produces the primary thrust. This is hydrodynamic mechanism undulating ribbon-fin propulsion. The streamwise vortexes mainly induce the vertical jet, which generates the primary heave force. The effect on hydrodynamics of main geometry and movement parameters including wave length, amplitude and advanced coefficients is investigated. A bionic underwater robot with bilateral undulating ribbon-fins is designed, and its navigation performance and maneuverability are measured.

Keywords : bionic propulsion, mobile robot, underwater robot, undulating ribbon-fins
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