Abstract

In this research, a numerical simulation method is employed to simulate a flapping movement for a flexible slender swimmer in a fluid. Our objective is to study dynamic behaviors of the flapping movement. Fig. 1 shows a sketch of the simulation: the leading edge of the swimming body is swung in the vertical direction to generate a horizontal thrust force, which drives the body itself to cruise in the horizontal direction in a fluid. The simulation is based on a combination of three numerical methods: the Lattice Boltzmann Method (LBM), Lattice Spring Model (LSM), and Immersed Boundary Method (IBM). The results show that two characteristics of the swimmer, flexibility and inertia, affect the swimmer cruising direction and performance. Illustrations are given in this study to explain the underlying mechanism of these phenomena.

Results

Feasibility of forward cruise

In the first portion, we only focus on the forward swimming. To evaluate the effect of the flexibility on the forward swimming performance, the average cruising speed as a function of rigidity is computed, as shown in the Fig. 5a. The trend in this figure is that the speed increases as the rigidity increases, and the speed arrives at a global maximum at an intermediate rigidity. Then, the speed decreases as the rigidity continues to grow. Fig. 5b shows the average speed against the reduced frequency, i.e., the ratio of the driving frequency and natural frequency. The optimal swimming performance can be achieved when the driving frequency is close to the natural frequency. This is known as resonance.

Cruise reversal and deformation

When the rigidity is large, the flapping motion of a slender swimmer propels itself swimming forward. However, as the rigidity continuously decreases, the swimmer may reverse its cruising direction and move backward (see Fig. 6). Deformations of the forward cruise and backward cruise are very different, as shown in Fig. 7. With a low rigidity, the swimmer body is very soft so that it deforms dramatically, resulting in a snake shaped body. The different shapes affect hydrodynamic forces and fluid fields.

Conclusions

- Two cruise states (forward or backward) do exist and are can be manipulated by varying the swimmer’s rigidity and inertia.
- The rigidity is systematically varied at different levels, and then the average cruising speed is computed. The optimal cruising performance do exist.
- The deformations of forward and backward movements are very different. The snake-like swimming body and the “sucking effect” of vortexes can explain the mechanism of the backward cruise.

References