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Inertia-Induced Synchronization of Undulatory Swimming

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ABSTRACT

The ubiquitous cooperative locomotion in a fluid has long been considered to gain evolutionary advantages by increasing the efficiency of the living creatures. Synchronization between undulatory swimmers, such as spermatozoa and eels at low and high Reynolds numbers respectively, has attracted much attention for its theoretical importance in fluid dynamics. Such swimmers propel themselves by generating travelling waves along their bodies or flagella. To understand the hydrodynamic interaction between the waving motions, we numerically and analytically study the infinite 2D waving-sheet model introduced by Taylor using the method of perturbation on the basis of small amplitude [1]. Previous studies have shown that at a zero Reynolds number, two sheets swimming close to one another do not have a preferred phase difference in a Newtonian fluid [1]. However, the two sheets will reach a stable in-phase synchronized state under the influence of elastic effect, either form the swimmer body or the viscoelastic fluid [2,3]. Since the inertia effects is not negligible for larger swimmers, we study the synchronizing behavior of undulatory swimmers at a finite Reynolds number. Our analysis show that the swimmers would eventually reach an anti-phase configuration, which is in contrast with previous studies. Propulsion velocity and time evolution are also studied across different parameters, showing that increasing the Reynolds number and decreasing the distance of the sheets can reduce the time to reach the final synchronization. The swimming speed of the swimmers increases through synchronizing, compared to the individual swimming. By performing numerical simulations of swimming sheets of arbitrary amplitudes, we find that above a critical separation distance h between the two sheets, the maximum velocity difference increases with decreasing h, which is consistent with the theoretical prediction. Below the critical distance, the maximum speed difference decreases with decreasing h, indicating there exists an optimum separation for the swimmers reaching the fastest synchronization.

KEYWORDS

Cooperative locomotion; flagellar swimming; inertia; synchronization

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