

PROCEEDINGS

An Analysis Method for Energy Transfer Characteristics Calculating During Live Zebrafish C-Turns

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ABSTRACT

The energy efficiency of current man-made underwater vehicles is far inferior to that of fish such as zebrafish. The exceptionally high propulsive efficiency of zebrafish swimming is primarily attributable to the flexible deformation of their bodies and the complex synergistic interactions between this deformation and the surrounding hydrodynamic flow field [1,2]. Through rhythmic undulatory movements generated from the trunk to the tail, zebrafish are able to effectively utilize fluid vortices to generate forward thrust, thereby achieving efficient energy conversion whilst reducing hydrodynamic drag [3-5]. To this end, this study quantitatively calculates various energy parameters involving the fish body and the flow field during zebrafish swimming, thereby investigating in depth the mechanisms of energy transfer and conversion between the two.

In this study, Particle Image Velocimetry (PIV) experiments were conducted to collect image data of zebrafish motion and velocity field data of the flow field. For the motion image data, we combined deep learning algorithms with post-processing routines to extract kinematic information. This was integrated with various smoothing methods to ensure data stability and physical continuity, thereby enabling precise quantification of the zebrafish's kinetic energy and the elastic energy generated by body bending. For the velocity field data, a divergence analysis was first conducted to confirm compliance with the incompressibility condition. Subsequently, we calculate the fluid kinetic energy and differentiate the velocity field to obtain the vorticity field, from which we further derive the dissipative power and compute the total energy dissipation in the flow field. We found that during the initial deformation phase, a significant portion (approximately 50%) of the active work performed by the muscles is converted into elastic potential energy stored within the fish's body; Subsequently, the accumulated elastic potential energy is rapidly released, causing a peak increase of 1×10^{-5} J in translational kinetic energy, whilst rotational kinetic energy decreases in tandem with the elastic rebound. During the subsequent reverse swing, both quantities increase again, reaching a second peak simultaneously. Furthermore, analysis of flow field dissipation indicates that the viscous dissipation energy irreversibly transferred to the surrounding environment during the zebrafish's bending and rebound process accounts for less than 5% of the fish's kinetic energy, maintaining a low level of energy loss. This study analyses the energy transfer processes during zebrafish swimming, providing a basis for elucidating the mechanisms of efficient propulsion in fish.

KEYWORDS

Live fish swimming experiment; zebrafish C-turn; deep learning algorithm; energy transfer and conversion

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