Hydrodynamic Experimental Investigation On Efficient Swimming Of Robotic Fish Using Self-propelled Method

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ABSTRACT

Efficient swimming of biologically carangiform robotic fish has been investigated by using a novel experimental method, the laboratory robotic fish model which follows an exact replica of Saithe, is self-propelled on a servo towing system. The forward towing speed is determined by the fluid force acting upon the robotic fish, as the fish undulate its body in the water. The importance of the self-propelled method which allows for simultaneous measurement of internal and external force of robotic fish has been demonstrated in the hydrodynamic experiment. Hydrodynamic result shows that the optimal swimming pattern of robotic fish is found at parametric value where Strouhal number(Triantafyllou G.S. et al.,1993), which can be defined as:

\[ St = \frac{2fh}{U} \]  

Where \( f \) denotes the tail beat frequency, \( h \) represents the maximum lateral excursion of the tail end over a cycle. \( St \) number is used to describe oscillating mechanism which serve to judge the flow, sufficient work has shown that animals using oscillatory or waving cruise with kinematics configured to operate with a Strouhal number in a narrow range (0.2<\( St < 0.4 \)) associated with efficient thrust production over wide range of swimming speed (Taylor, G.K et al., 2003; Wolfgang M.J. et al.,1999 ), fish also tune their kinematics in different constrained flow to produce an optimal wake for maximal hydrodynamic efficiency.

(2) Dimensionless body wave speed \( \delta \) (Muller UK et al.,1997), which is defined as:

\[ \delta = \frac{V}{U} \]  

It represents the ratio of the body wave speed \( V \) to the swimming speeds \( U \), note that live carangiform swimmers always cruise at a \( \delta \) of slightly greater than 1.

(3) Dimensionless amplitude \( h \) ( Hess and Videler, J.J, 1999), defined as:

\[ h = \frac{A_{\text{max}}}{L} \]  

where \( A_{\text{max}} \) represents the maximum lateral excursion at the tail end during flapping, the dimensionless amplitude of carangiform fish during steady swimming is normally 0.08–0.12(Videler J J. 1993).

Although the relationship between efficient swimming and dimensionless parameters has been widely studied, the corresponding dimensionless parameters of robotic fish with optimal swimming are

INTRODUCTION

Through bionic engineering, the high thrust performance of fish is used to make up for the defects in traditional underwater vehicle, especially low efficiency. In this paper, we choose to imitate the carangiform fish which belongs to the BCF(Body/Caudal Fin propulsion) swim pattern(Sfakiotakis et al., 1999). Undulate swimming of carangiform can be conceptualized as the action of two waving plates, one plate being positioned in the wake of the other(Muller UK et al.,1997,2000,2001), the tail corresponds to the downstream waving plate, while the body is the upstream waving plate, both of the two plates will infer the thrust efficiency of fish by combination of two major flow mechanism: 1. Reasonable body waving to produce minimum drag(Taneda et al., 1974), 2. Proper caudal fin movement to generate maximum thrust force according to vorticity control(Anderson et al.,2002; Barrett et al., 1999; Nauen J C and Lauder G V et al., 2002; Lauder G. V. and Drucker 2002; Cheng J-Y et al., 1994, Lighthill 1970).

Sufficient previous researches provide evidence that the dimensionless parameters are closely related with fish efficient swimming(Triantafyllou M.S et al.,2000; Taylor G.K et al., 2003).

When the vorticity mode of fish swimming “footprint” is too difficult to establish its mathematical analytical equations or obtain a dynamic model, hydrodynamic experiment analysis using dimensionless parameters becomes a powerful scientific solution(Hoerner et al., 1965). Reasonable dimensionless parameters will make swimming fish generating optimum vorticity distribution and intensity(Tytell E.D et al., 2004), thus, which give higher efficiency for the swimming. Several key dimensionless parameters are considered in our research: (1) Strouhal number(Triantafyllou G.S. et al.,1993), which can be defined as:

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Where \( f \) denotes the tail beat frequency, \( h \) represents the maximum lateral excursion of the tail end over a cycle. \( St \) number is used to describe oscillating mechanism which serve to judge the flow, sufficient work has shown that animals using oscillatory or waving cruise with kinematics configured to operate with a Strouhal number in a narrow range (0.2<\( St < 0.4 \)) associated with efficient thrust production over wide range of swimming speed (Taylor, G.K et al., 2003; Wolfgang M.J. et al.,1999), fish also tune their kinematics in different constrained flow to produce an optimal wake for maximal hydrodynamic efficiency.