Numerical Simulation and Experimental Study on Drag Reduction of Circular Cylinder Using Bionic Method

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ABSTRACT

In this paper, a three-dimensional cylinder model was designed using bionic method based on the plumage and fin of animals. After appropriate simplification, geometric parameters of models were given. Numerical simulation was then used to compute the hydrodynamic performance of different bionic cylinders. By comparing the results with smooth cylinder, the mechanism of drag reduction for bionic cylinder was discussed. In order to validate the numerical method, a towing experiment was designed to measure the drag under different conditions. The research can provide references for the parametric designs of the bionic structures and shape optimizations.

KEY WORDS: bionic model; drag reduction; numerical simulation; towing test.

INTRODUCTION

Drag and noise reduction are the research hotspots and goals for scientific and engineering areas, particularly in the fields of marine, land transport, and aerospace. After billions of years of biological evolution and natural selection, many animals can fly or swim with high efficiency and low drag by active and passive flow control (Walsh, 1982; Gadelhak, 1996; Kim, 1999; Sohankar, A, 2015; Rastan, MR, 2018). For active control, a typical example is that the fish can swim efficiently by using flexible fin and body. Also, some animals like shark and owl use passive flow control to reduce drag and noise during locomotion by relying on the structural and morphological components of the body. Fig.1 shows some typical features of these animals in the air and water. The structures on the surface of flying animals effectively reduce the air resistance during flight, and even decrease vibration and noise. Also, Studies have shown that the dorsal fins of some fish and mammals like humpback whale in the water have similar non-smooth shapes and structures, which play an important role for high speed swimming. The morphological features of animals for flow control can be utilized in the biomimetic design of engineered structures for increased power production and reduced resistance. For underwater vehicles, there are many cylindrical structures such as antennas and lift platforms, which will induce high resistance and noise under high speed. The bionics can provide some ideas for the designs of underwater structures comparing with complex theoretical analysis.

Fig. 1 morphological features of animals (left: wing of bird, middle: fin of fish, right: fin of humpback)

In order to put these morphological features into engineering application, researchers usually first analysis the special features like non-smooth surface, then they combine the practical objects to design the biomimetic structures and study the flow characters by theoretical calculation, experimental measurement and numerical simulation.

In recent years, many studies had been done to reduce the flow resistance and noise of engineering structures inspired by high efficiency and quiet biology (Yong, 2004; Su et al., 2009; Bhushan, 2012; Epstein, 2012; Shi et al., 2012; Wen et al., 2014). Wang proposed a biomimetic airfoil based on the bionic flow control concept with leading edge waves, trailing edge serrations, surface ridges and each section reflecting the conventional NACA 0012 airfoil profile, which achieved the reduction of aerodynamic noise (Wang, 2017). Inspired by the riblet structures of shark skin, Bhushan proposed a bionic method as one of the flow control methods to reduce the fluid-drag (Bhushan, 2010). Cui found that a serrated structure arranged on both sides of the cylinder had a significant influence on the hydrodynamic and hydroacoustic performance by controlling the fluctuating lift force induced by unstable vortices acting on the cylinder surface so that the hydrodynamic noise of the cylinder can be reduced (Cui et al., 2018). Dou analyzed the surface microstructure of fish and proposed a comparable bionic surface mimicking fish scales fabricated...