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Propulsive Characteristics of Twin Oscillating Airfoils

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Abstract

The bionic propulsion can be used on the aerostat and other automatic vehicles. The general single oscillating tail fin can induce the yawing and whole airship rolling because of the lateral force and the gravity moment of heavier oscillating tail fin. The parallel twin oscillating tail fins by symmetrical swing mode can eliminate the lateral force and gravity moment through the symmetrical swing of the two tail fins. The propulsive characteristics of parallel twin fins have not been investigated up to now. In this paper, we investigated the propulsive characteristics and mechanism of parallel twin oscillating airfoils using consistent and symmetrical swing mode. By using the numerical calculation and analysis, the consistent swing mode may decrease the total propulsion efficiency. While, the symmetrical swing mode can improve the propulsion efficiency and reduce the lateral force and gravity moment. This mode can be used to propel the aerostat and automatic underwater vehicles efficiently.

Keywords: propulsive characteristics, oscillating airfoils, bionic propulsion, Computational Fluid Dynamics (CFD), swing mode, ground effect

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1 Introduction

The aerostat usually use the propeller as the driver. But the propeller can only obtain the optimum propulsive efficiency under the condition of a certain design point. Because of the random wind field of atmosphere environment and other factors (such as the change of local flow field on the installation location of propeller), the propeller state of aerostat may deviate from the design flight state; the propulsion efficiency of propeller can be decreased largely. Moreover, the general propeller propulsion has some limits[1]. There are some studies about the propulsive characteristics of imitating fish propulsion using the single fin to propel ships and automatic underwater vehicles. The fish propulsion mode can also be used to drive the aerostat,. Fish propulsion mode has the advantages of high efficiency[2], easy to achieve self-adaption, high mobility and no noise.

There are some studies about the propulsive characteristics and mechanism of fish, bird, insect and bionic investigations through experiments and numerical methods[3,4]. These generally include two dimensional single oscillating airfoil, three dimensional (3D) oscillating flap and multi-oscillating airfoils.

The different Navier-Stokes solver was mainly used to the investigation of two dimensional (2D) oscillating airfoils. Tuncer and Kaya[5] studied the optimization of flapping airfoils for maximum thrust and propulsive efficiency. Young and Lai[6] analyzed the influence mechanisms of propulsion efficiency of oscillating NACA0012 airfoil. Guerrero[7] studied the effect of airfoil cambering. Yang *et al*.[8] studied the propulsion characteristics of flexible NACA0012 airfoil with different parameters. Spagnolie *et al*.[9] studied a freely moving wing that can “pitch” passively as it is actively heaving in a fluid through experiment and numerical simulation. Le *et al*.[10] investigated the aerodynamic performance of the flapping wing with different chord flexures. Wu *et al*.[11] investigated the fluid dynamics of flapping insect wing in ground effect. Moore[12] developed small-amplitude theory to model a flapping wing that pitches passively due to a combination of wing compliance, inertia, and fluid forces and obtained a class of exact solutions. Moore[13] also examined how thrust depends on the chord-wise distribution of wing stiffness using 2D small-amplitude theory and a fast Chebyshev method.

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In 3D oscillating flap aspect, Moelyadi and Sachs[14] obtained the dynamic yaw stability derivatives of a gull bird using numerical algorithm and two different motions. Bai *et al*.[15] computed the power requirements of pitching-down flapping of the model wing of fruit fly. Sachs and Moelyadi[16] studied the effects of extremely large dihedral on the aerodynamic characteristics of birds. Cheng and Lan[17] constructed a simplified 3D model and identified the role of the chordwise flexibility in full flapping motion. Zhou *et al*.[18] investigated the hydrodynamic mechanism of caudal fin propulsion by numerical simulations.

In the twin and multi-oscillating airfoils aspect, Platzer *et al*.[19] described a panel code that can systematic study of the thrust and lift characteristics produced by oscillating airfoils and airfoil combinations in incompressible inviscid flow. Triantafyllou *et al*.[20] pointed out the non dimensional frequency of maximum amplification (Strouhal number) is in the range of 0.25 to 0.35. This result was verified by experiments and a large number of data from observations on fish and cetaceans. Jones and Platzer[21] investigated flapping-wing propulsion for several geometrically simple configurations (single airfoil case, two airfoil system, airfoil in ground effect) by experiment and numerical method. Jones and Platzer[22] investigated the flapping-wing configurations found numerically to produce high propulsive efficiencies through the experiment. Jones *et al*.[23] investigated flapping-wing propulsion in ground effect by experimental and numerical methods. Ristroph and Zhang[24] investigated ‘schooling’ flapping flags using experiments. Zhu[25] designed and performed a series of numerical simulations on the interaction of a pair of tandem flexible flags separated by a dimensionless vertical distance in a flowing viscous incompressible fluid at lower Reynolds numbers using the Immersed Boundary (IB) method.

However, no systemic investigation has been performed so far to analyze the propulsion characteristics of parallel twin oscillating airfoils. Jordi1 *et al*. [26] studied the realistic method of fish propulsion on aerostat using the single fin.

In this paper, we investigated the propulsive characteristics of parallel twin oscillating airfoils using the Computational Fluid Dynamics (CFD) method. The method was verified through the experiment results of oscillating foil with NACA0012 airfoil. Then, the propulsive characteristics and mechanisms of parallel twin oscillating airfoil by two swing modes were analyzed. These results can be used to design the aerostats that are driven by oscillating airfoils.

The remains of this paper are organized as follows: The swing mode and numerical method were described in section **2**. In section **3**, the propulsive characteristics of consistent and symmetrical swing mode under the conditions of different nominal distances between two airfoils were analyzed. The mechanisms of swing mode of parallel two airfoils were analyzed in section **4**. In section **5**, we draw conclusions of the propulsive characteristics of parallel twin oscillating airfoils.

2 The swing mode and numerical method

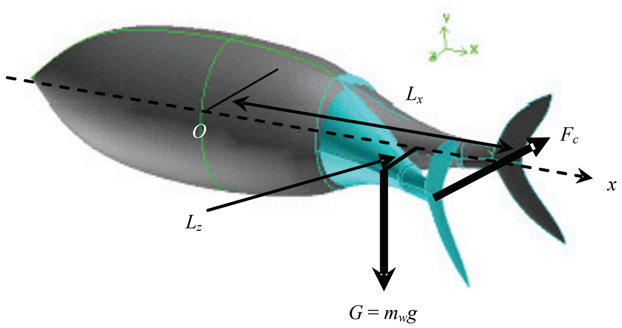
2.1 The swing mode

For the aerostat, the single oscillating tail fin may induce lateral force and gravity moment as shown in Fig. 1. While the parallel twin oscillating tail fins with symmetrical swing mode can eliminate the lateral force and gravity moment. This is the reason why we investigate the twin oscillating airfoils.

For systematically obtaining the propulsive characteristics of twin oscillating airfoils, the consistent swing mode and the symmetrical swing mode (shown in Fig. 2) were investigated.

2.1.1 The consistent swing mode

The consistent swing mode in the initial time $t = 0$, the heave and pitch motions of a single airfoil are shown in Fig. 3. The two airfoils have the same heave and pitch motions:



$M_{x\_roll} = m_w g \cdot L_z \quad M_{y\_bow} = F_C \cdot L_x$

Fig. 1 The lateral moment M_{y_bow} and gravity moment M_{x_roll} by the single oscillating tail fin.