Ocean Engineering 138 (2017) 112–122

Contents lists available at ScienceDirect

Ocean Engineering

journal homepage: www.elsevier.com/locate/oceaneng

A fully-activated flapping foil in wind gust: Energy harvesting performance investigation

Yongliang Chen[a], Jiapu Zhan[a], Jie Wu[a,b,*], Jing Wu[a]

[a] Department of Aerodynamics, Nanjing University of Aeronautics and Astronautics, Yudao Street 29, Nanjing, Jiangsu 210016, China
[b] Jiangsu Key Laboratory of Hi-Tech Research for Wind Turbine Design, Yudao Street 29, Nanjing, Jiangsu 210016, China

ARTICLE INFO

Keywords:
Fully-activated
Flapping foil
Wind gust
Energy harvesting performance

ABSTRACT

The energy harvesting performance of a fully-activated flapping foil under wind gust conditions is numerically investigated in this work. A NACA0015 airfoil performs the imposed heaving and pitching motions. The wind gust is modeled as a single frequency harmonic oscillation, and there is a phase difference between the wind gust and the pitching motion of the foil. To conduct numerical computations, the commercial code FLUENT together with the dynamic mesh strategy are adopted. At a Reynolds number of 1100 and the position of the pitching axis at one-third chord, the effects of the gust frequency, the oscillation amplitude of gust, and the phase difference between the gust and the pitch are systematically examined. By comparing with the results from the uniform flow, it is found that the energy harvesting efficiency under wind gust conditions can be changed greatly. Particularly, when the phase difference is in the range of 90° and 270°, a higher energy harvesting efficiency is produced, which is attributed to the increased lift force as well as the good synchronization between the lift force and the heaving velocity.

1. Introduction

In the past decades, wind and tidal stream energy converters have become a major focus for renewable energy research. The majority of existing designs for tidal energy devices utilize either horizontal-axis or vertical-axis turbine-based energy converters. On the other hand, with the development of flying frequency and mode, insects and birds are capable of enhancing lift and thrust by extracting energy from the surrounding flows, especially the vorticity fields (Anderson et al., 1998; Wang, 2000). Based on a similar principle, a new type of flapping foil based power generation system which mimics insect flight has been proposed. Compared with conventional energy harvesting devices such as the horizontal-axis rotor turbines, the flapping foil system has a number of advantages. For example, due to the relatively low tip speed, these foils generate less noise than rotor blades and reduce impact on the navigation of aquatic animals. Without the centrifugal stress associated with rotating blades, the oscillatory devices are structurally robust (Kinsey and Dumas, 2008).

The study of flapping foil based flow energy harvester started with the experimental work by McKinney and DeLaurier (1981), which proved the feasibility of flow energy extraction by a harmonically oscillating wing. Their prototype contains a foil undergoing pitching and heaving motions. Following that idea, Jones and Platzer (1997) examined the transition from thrust generation to power extraction by using an unsteady panel code coupled with a boundary layer algorithm. They demonstrated that pitching/heaving foils could be used both as propellers and as energy harvesters, depending on the range of kinematic parameters. After these pioneering studies, an important focus of the following work is to identify the optimal combination of kinematic parameters that lead to the best performance of the system. As a result, this novel system can compete with the traditional designs based on rotating blades.

From both experimental measurements and numerical simulations using an unsteady panel code, the results obtained by Davids (1999) show that the efficiency of energy extraction with an oscillating NACA0012 foil can reach 30% with optimized combination of heaving amplitude and frequency. More systematic numerical and experimental investigations were carried out by Lindsey (2002) on a twin-wing system and Jones et al. (2003) on a single-wing system. Recent computational efforts by Dumas and Kinsey (2006) and Kinsey and Dumas (2008) presented a mapping of energy-extraction efficiency for an oscillating NACA0015 foil in the frequency and pitching amplitude domain. Both pitching and heaving motions are sinusoidal. The maximum power harvesting efficiency was found to be 34%, achieved at pitching amplitude of 75° and non-dimensional frequency of around 0.15 (hereby the frequency is normalized by the chord length and the

---

[*] Corresponding author at: Department of Aerodynamics, Nanjing University of Aeronautics and Astronautics, Yudao Street 29, Nanjing, Jiangsu 210016, China.
E-mail address: wuj@nuaa.edu.cn (J. Wu).

http://dx.doi.org/10.1016/j.oceaneng.2017.04.027
Received 9 June 2016; Received in revised form 13 February 2017; Accepted 20 April 2017

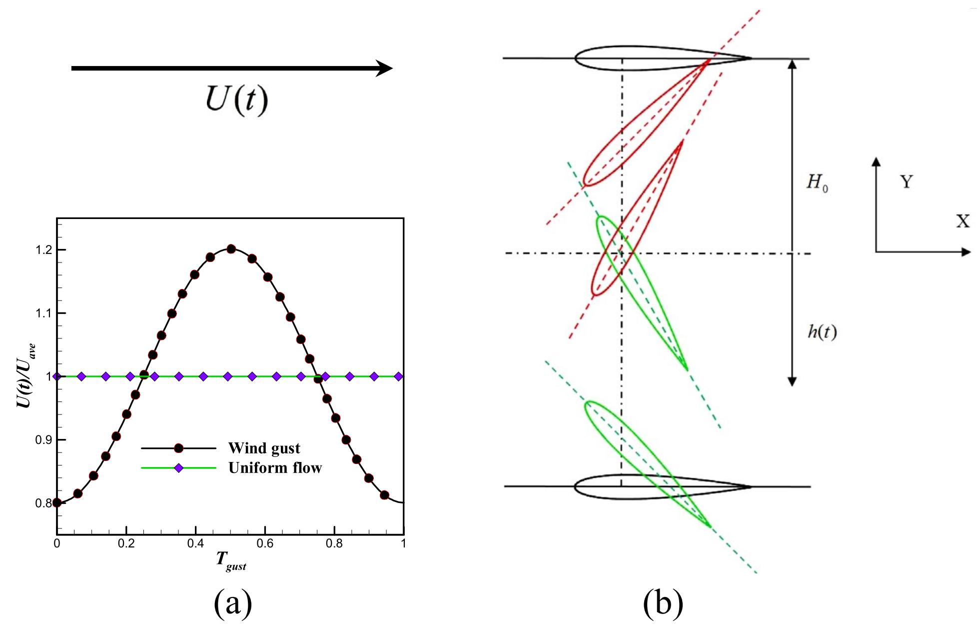

Fig. 1. Sketch of (a) non-dimensional incoming flow velocity and (b) motion of the foil.

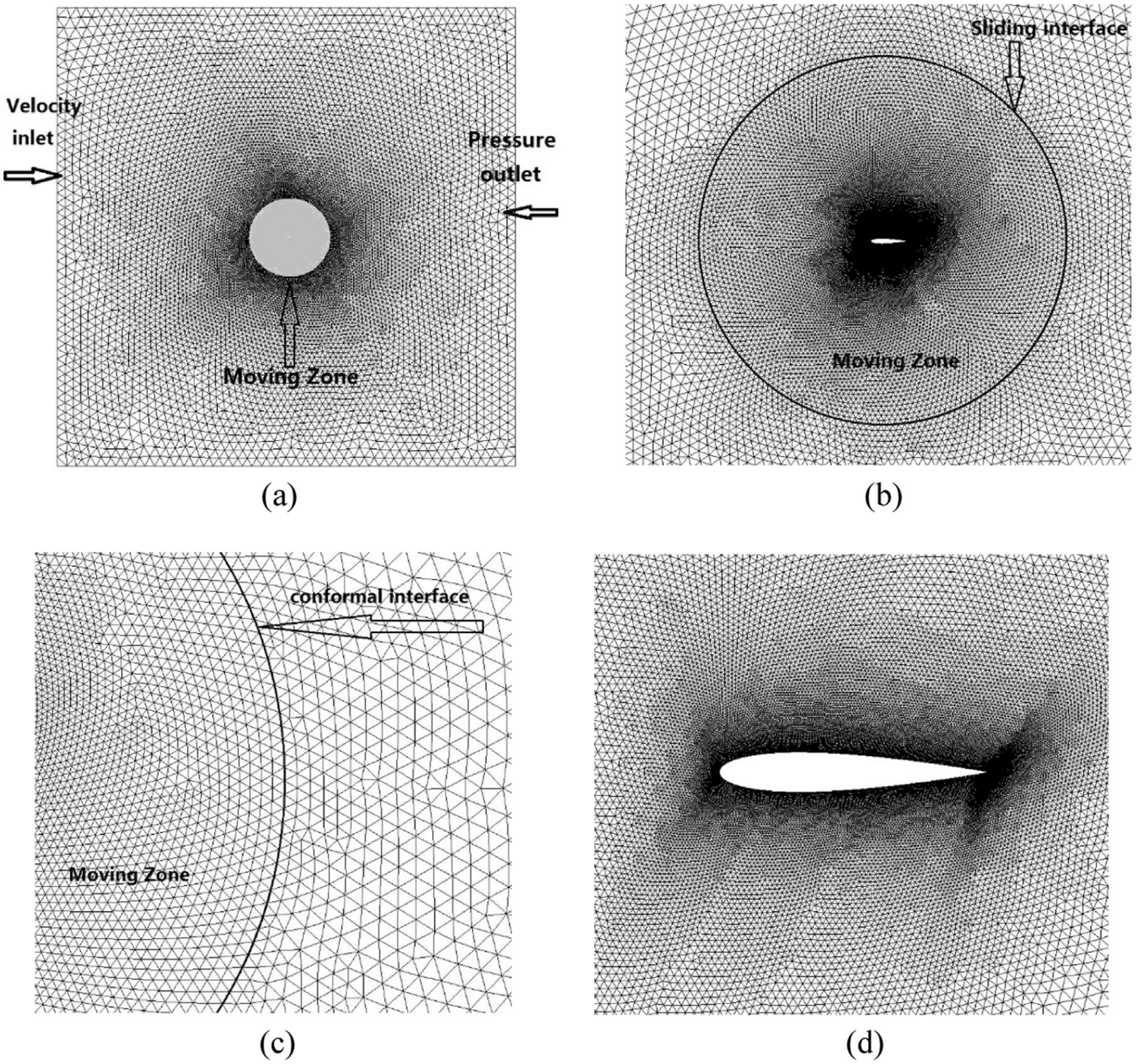

Fig. 2. (a) The overall view of the computational domain; close-up view of: (b) the oscillation domain; (c) the conformal sliding interface; and (d) the mesh near the foil.