Energy 118 (2017) 147–155

Contents lists available at ScienceDirect

Energy

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

A Turbosail profile analysis code based on the panel method

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ARTICLE INFO

Article history:
Received 1 July 2015
Received in revised form
6 December 2016
Accepted 12 December 2016
Available online 18 December 2016

Keywords:
Turbosail
Panel method
Suction
Flap
Lift
Drag

ABSTRACT

With the soaring of fuel prices and the increase of environmental issues, research in the field of wind power has known a significant growth around the world. The new concept of the Turbosail has been introduced, but did not reach the practical use stage. Despite its practical interest, little work has been conducted on the Turbosail in the recent years.

The aim of this paper is to develop an accurate numerical code, based on the singularities method, for the Turbosail analysis and applications. The effects of thickness, suction and flap deflections on the aerodynamics performances of Turbosail profile are studied. The simulation results show that the flap plays an important role in increasing the lift. On the other hand, at high deflection angles, it is generally ineffective for drag reduction. It is found that the suction decreases significantly the drag and causes a little increase in lift. The main conclusion is that, the incorporation of the flap and the suction effect doubly enhance the Turbosail efficiency by increasing its lift and reducing its drag respectively. These results are very important and provide the impetus for developing; the simple design equations and applications for the Turbosail.

1. Introduction

Research in the field of wind power is growing worldwide. The aerodynamic innovation and the technological development of wind energy conversion systems are always focusing on optimizing the existing profile shapes or on designing new profile forms [1]. In both cases the aerodynamicists are trying to improve the present limits of performance. Advances have been made in different aspects related to this technology. One of these has been the return to the use of Magnus effect to produce high lift forces from rotating cylinders [2]. Seifert [3] and kazemi [4] have extensively reviewed the recent application of Magnus forces in naval or wind turbine applications. The first successful device based on Magnus effect returns to the year 1924, when Anton Flettner has proposed his first ship, Buckau, operating with two vertical rotating cylinders, instead of sails [5]. The renew attention in the Flettner type rotor is becoming again a hot topic in the areas of naval and wind turbine applications [5]. Its potential has attracted many researchers in different fields of Engineering [3].

Although the Magnus effect creates high lift coefficients, this is counteracted by significant mechanical complications on the rotating cylinder, introduced by vibrations and gyroscopic effects [6]. In this context, the Cousteau Foundation has manufactured a new system, much simpler and more reliable than the Magnus rotor: the orientable aspirated cylinder, named Turbosail [7]. The system offers a lift force close to the Magnus rotor lift [8] which is up to four times better than that of the best modern wing sails [9], but it was unable to get to the practical or commercial use [10].

The Turbosail essentially consist of a vertical cylinder, with elliptic cross section. It also has longitudinal suction areas on the leeward side and a movable flap on the lower side of the trailing edge [11]. This device creates a net circulation, generating a high lift for propulsion of any mobile device or equipment such as a ship [6].

Perhaps one of the first successful device based on Turbosail principle dated back as early as 1982 by Malavard and his co-workers [11] for application in naval design. Malavard et al. [7] has prototyped and tested a Turbosail consisting of a vertical aspirated cylinder of 13.5 m height, mounted on a catamaran christened "Moulin à Vent". Their experimental studies suggested the remarkable efficiency of the propeller. Subsequently, Cousteau et al. [12] has benefited from the development of the original inventation "Moulin à vent" and has designed a specific experimental ship, "Alcyone" fitted with two Turbosails of 10.25 m height. Cousteau concluded an agreement on the industrial and

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http://dx.doi.org/10.1016/j.energy.2016.12.044
0360-5442/

Nomenclature

C_l	*lift coefficient*
C_d	drag coefficient
C_p	pressure coefficient
C_q	suction coefficient
V_∞	free stream velocity
V_{suc}	sucked velocity
u, v	velocity component in x and y axis system
u_{sij}, v_{sij}	influence of panel j in panel i due to a source
u_{vij}, v_{vij}	influence of panel j in panel i due to a vortex
q	source strength
γ	vortex strength
c	chord length
N	Number of panel
α	angle of incidence
β	flap's angle orientation
θ_i	panel's angle orientation
i	receptor point
j	inductor point

commercial exploitation of Turbosails [12].

Recently, Hcini et al. [11] has proposed an efficient numerical code, for the prediction of the aerodynamic characteristics of Turbosail type wind turbine with very thick aspirated profiles. A vortex model has been treated based on the lifting line theory. The results predicted by the code developed, have been compared and validated by some numerical and experimental data.

Guerri [13] has developed two-dimensional Navier-Stokes model for flow around a thick profile similar to that used on the Alcyone, with the Reynolds number of 10^5. The profile is equipped with suction grid along the span. The results, presented at zero and 15° angle of attack, demonstrated that the suction presents a double effect: first, it improves the performance and the lift to drag ratio. Second, it suppresses the vortex sheddings.

Fournier [14] has reported a Large Eddy Simulation for flow over an aspirated circular cylinder without flap, concluding considerable decrease in drag force up to 30%.

Shiii et al. [15] has designed a propulsion assistance system (C-PAS) for Ships composed of a circular cylinder with a triangle tail flap and air suction area. Flow visualization by smoke test was conducted at a two dimensional wind-tunnel and the results demonstrated the clear effect of air suction in increasing the lift to 3.5. He has conducted an X-type hot-wire measurements to measure flow velocity and direction more in detail around the cylindrical sail with a fin [16].

In the experimental study by Low [17], the effects of suction and flap locations on the performance of a wind-assisted ship propulsion device with circular profile, were examined. The measurements showed that a lift coefficient of 4.2 can be achieved at the optimum conditions of flap deflections and suction locations. His findings suggest that a good performance can be obtained by optimizing only the suction angle.

Lucien Malavard mentioned that the Turbosail can be used to constitute the blade of a horizontal axis wind turbine [11]. In this regard, Lemaigre et al. [18] has presented an experimental methodology on optimizing a blade wind turbine equipped with four Turbosails instead of traditional blades. He concluded that the rotor has efficiency nearly as good as the best three-blade turbine. However, the major researches on Turbosail principle were focused on the areas of naval applications.

The most important experimental work on Turbosail was done by the Cousteau Foundation [11]. Experimental results of the lift drag and pressure distribution have been presented for a Turbosail with a forward ovoid profile with a relative thickness of 66%. All the results were presented for the flap fixed at an angular position of 45° from the chord line. The thickness effect was not presented and the pressure distribution was presented only at a zero-angle incidence [17]. However, the effect of the flap deflection was not investigated for a case without suction.

The most important theoretical study on the Turbosail documented in literature is attributed to A. Daif [12]. He developed a numerical model based on the standard transformation of the profile into a circle with a fixed point, determined experimentally to simulate the effect of the flap. His model gave the variation of the lift coefficient with to the angle of incidence and also the pressure distribution at different values of lift. In another study, A. Daif [19] also has presented a mathematical model based on the lifting line theory for evaluating the Turbosail interactions for windship propulsion.

Despite their practical interest, researches on the Turbosail model have mostly been geared towards experimental studies and only a few examples can be found in practice [9]. In addition, few theoretical studies of thick airfoils have been conducted in the recent years, particularly for the Turbosail airfoils [11].

The purpose of this study is to examine the independent effects of the suction and the flap deflections on the pressure distribution, lift and drag of a Turbosail profile. The variation of the flap deflections for a case without suction is studied; this might clarify whether a satisfactory performance can be attained by using the flap only. We also investigate the thickness effect in the Turbosail profiles family.

A numerical model, based on the panel method, has been developed to calculate the flow around the Turbosail profile. The panel theory is very efficient for modelling rotor dynamics including marine propellers and wind turbines [20]. It is based on the representation of the profile geometry using surface panels of source–doublet–vorticity distribution [21].

The present simulation was accomplished by extending the Hess Smith panel method to include the effect of suction, which is obtained by specifying a normal velocity characterized by a suction coefficient C_q on the suction panels. The flap effect is carried out by applying the Kutta Joukowski condition at the immediate extension matching its orientation. The versatile Neumann boundary condition, applied over the solid body has been used in the modelling. The resolution of the field problem yields the source–vortex distributions and the velocity distributions over the contour of the airfoil. The numerical model is flexible, providing the possibility to generate the geometry of the Turbosail profile so we can vary each time the relative thickness, the flap angle, the suction location and the intensity of the quantity of air sucked. The influence of the various parameters on the evolution of the lift and of the drag coefficients is presented. Theoretical and experimental results from the literature were confronted to validate the numerical flow model.

2. Methods

The Hess-Smith panel method consists of discretizing the contour of the profile into a series of small segments in order to approach as good as possible the actual contour. The development of this method is characterized by a distribution of sources and vortices on each panel to model the flow. The source strength is constant over each line segment but has a different value for each segment while the vortex strength is constant and equal over each line segment. For a detailed description of the two-dimensional