Ocean Engineering 90 (2014) 39–48

Contents lists available at ScienceDirect

Ocean Engineering

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

Kite and classical rig sailing performance comparison on a one design keel boat

R. Leloup [a,b], K. Roncin [b,*], G. Bles [b], J.-B. Leroux [b], C. Jochum [b], Y. Parlier [a]

[a] *OCEA, rue des Terres Neuves, BP 21, 33322 Bègles Cedex, France*
[b] *Mechanics of Naval Structures, LBMS (EA 4325) ENSTA Bretagne, 2 rue François Verny, 29806 Brest, France*

ARTICLE INFO

Article history:
Received 15 November 2013
Accepted 27 June 2014
Available online 8 August 2014

Keywords:
Dynamic simulation
Wind energy
Kite
Kiteboat
Sailboat
Velocity prediction programme

ABSTRACT

An implementation of a kite modelling approach into 6 degrees of freedom sailboat dynamic simulator is introduced. This enables an evaluation of kite performance in comparison with classical rig sailing.

A zero-mass model was used to model kite forces. Influence of the wind gradient was properly taken into account leading to significant modifications in the calculation of the relative wind. The modelling was performed with experimental aerodynamic characteristics. An optimization was done to determine the best kite flight trajectory in terms of performance.

Validation steps of the sail yacht simulator were performed for a classical rig on the example of an 8 m one design yacht. The experimental set-up is described and validation results are discussed. Particularly, a wind mesh was used, based on measurements made at four different locations of the navigation spot. Additionally boat motions were recorded by high resolution GPS and inertial unit systems.

Speed polar diagram results, reached by kite propulsion, were predicted versus true wind angle. At last a comparison was made for upwind and downwind legs in sea trials conditions, between simulations with the classical rig and the kite. It is shown that the boat towed by kite would achieve much better sailing performance.

© 2014 Elsevier Ltd. All rights reserved.

1. Introduction

Regarding world speed records, kite surfers demonstrated the performance efficiency of kites. In this context, taking advantage of wind using kites as propulsion systems for yachts can be an alternative to conventional sails. This study takes place within the project “beyond the sea®” launched by Yves Parlier and is managed in partnership with the LBMS laboratory of ENSTA Bretagne and the French ministry of defence.

A methodology for kite propulsion efficiency analysis regarding a classical rig sailing yacht is presented in this paper. The aim of the paper is to assess the benefits of the kite rig used for propulsion compared to the classical rig. In this framework, regarding the lack of data for the validation of kite rig propulsion models, the leading idea of the paper is to consider on one hand a VPP basis validated on a classical rig by sea trials and on the other hand, existing experimental aerodynamic properties of a flying kite (Dadd et al., 2010). Thus, replacing the classical rig part in the VPP scheme by the one, dedicated to the kite rig and using experimental aerodynamic coefficients, can reasonably be considered as a first predictive step for kite rig benefits. Of course, the next step should be the comparison of the kite benefits prediction with measurements. Consequently differences between the two propulsion technologies applied to the same yacht are highlighted and discussed. One of the first studies on kites and their ability to produce energy was achieved by Loyd (1980). More recently, the literature provides numerous articles which started to treat flight dynamics (de Groot, 2010; Terink, 2009), flight control (Fagiano, 2009), structure deformation (Breukels, 2011), or aerodynamic forces modelling (Maneia, 2007; de Wachter, 2008).

Despite very fine approaches have been achieved in order to model the kite's flight applying Newton's laws (Terink, 2009; Breukels, 2011) even taking into account kite's lines and mass distribution like de Groot (2010), the so-called zero-mass model (Wellicome and Wilkinson, 1984) remains well known and widely used as its simplicity makes it easy to connect with. Within this model, Newton's laws are applied considering only the aerodynamic resultant and tethers tensions, since the mass of the kite is neglected. Even recently, numerous studies dealing with flight strategies optimization for boat propulsion such as Wellicome and Wilkinson (1984), Naaijen et al. (2006, 2010), Dadd (2013) or with

---

[*] Corresponding author. Tel.: +33 2 98348748; fax: +33 2 98348730.
E-mail address: kostia.roncin@ensta-bretagne.fr (K. Roncin).
URL: http://www.parlier.org (Y. Parlier).

http://dx.doi.org/10.1016/j.oceaneng.2014.06.043
0029-8018/© 2014 Elsevier Ltd. All rights reserved.

Nomenclature

Notation – parameter (unit)

Notation	parameter (unit)
A_k	kite surface (m^2)
C_D	drag coefficient of the kite (dimensionless)
C_L	lift coefficient of the kite (dimensionless)
$\mathbf{D}$	kite drag vector (N)
D	kite drag magnitude (N)
$\mathbf{F}_a$	aerodynamic resultant vector (N)
F_a	aerodynamic resultant magnitude (N)
l_T	tethers length (m)
$\mathbf{L}$	kite lift vector (N)
L	kite lift magnitude (N)
n	coefficient which is equal to 1/7 for the sea surface according to ITTC (2011) (dimensionless)
$\mathbf{T}$	tethers tension vector (N)
T	tethers tension magnitude (N)
$\mathbf{U}_{10}$	true wind velocity vector at standard altitude (10 m) (m s^{-1})
U_{10}	true wind velocity magnitude at standard altitude (10 m) (m s^{-1})
$\mathbf{V}_a$	kite apparent wind velocity vector (m s^{-1})
V_a	kite apparent wind velocity magnitude (m s^{-1})
$\mathbf{V}_k$	kite velocity vector (m s^{-1})
V_k	kite velocity magnitude (m s^{-1})
$\mathbf{V}_s$	ship velocity vector (m s^{-1})
V_s	ship velocity magnitude (m s^{-1})
$\mathbf{V}_{WR}$	relative wind velocity vector at kite altitude (relative to boat course) (m s^{-1})
V_{WR}	relative wind velocity magnitude at kite altitude (relative to boat course) (m s^{-1})
$\mathbf{V}_{WT}$	true wind velocity vector (m s^{-1})
V_{WT}	true wind velocity magnitude (m s^{-1})
z	altitude above sea level (m)
$\alpha_{geom.}$	geometric incidence (rad)
β_{WT}	true wind angle (relative to boat course) (rad)
β_{WR}	relative wind angle at kite altitude (relative to boat course) (rad)
χ_{vk}	kite velocity angle (rad)
ε	kite lift to drag angle (rad)
θ	elevation angle (rad)
ρ_{air}	air density (kg m^{-3})
ϕ	azimuth angle (rad)

Reference frames

R_F $(O,\mathbf{x}_F,\mathbf{y}_F,\mathbf{z}_F)$	ship velocity reference frame
R_{WT} $(O,\mathbf{x}_{WT},\mathbf{y}_{WT},\mathbf{z}_{WT})$	true wind reference frame
R_{WR} $(A,\mathbf{x}_{WR},\mathbf{y}_{WR},\mathbf{z}_{WR})$	relative wind at kite altitude reference frame
R_{k0} $(K,\mathbf{x}_{k0},\mathbf{y}_{k0},\mathbf{z}_{k0})$	kite position reference frame
R_a $(K,\mathbf{x}_a,\mathbf{y}_a,\mathbf{z}_a)$	aerodynamic reference frame
R_b $(K,\mathbf{x}_b,\mathbf{y}_b,\mathbf{z}_b)$	body reference frame
$\mathbf{x}_{vk}$	kite velocity direction unit vector

real-time control for kites such as Erhard and Strauch (2013a)) or Costello et al. (2013), rely on this kind of zero-mass approach. In fact, its very low computational cost and its reasonable predictions regarding experiments balance out its high level of approximation. As few examples Wellicome and Wilkinson (1984) can be cited as they compared stationary and dynamic flight strategies applying them for boat propulsion. Dadd et al. (2010, 2011) studied dynamic flight with 8-shaped trajectories and obtained rather satisfactory comparisons with experimental measurements. Furthermore, Naaijen et al. (2006, 2010) developed a performance prediction programme dedicated to a merchant ship to assess fuel saving capabilities of a kite. The present study is inspired from previous works (Leloup, 2013a) which integrated an aerodynamic kite model within the zero mass model. This model also allowed to predict fuel saving on a 60,000 dwt tanker (Leloup et al., 2013b).

The modelling approach for a flying kite is presented in the first part of the study. The wind gradient linked to atmospheric boundary layer is taken into account, and analytical expressions for apparent wind velocity seen by the kite and for kite velocity at each position within the wind window are presented. An optimization technique for the best flight configuration is then proposed. Especially, this optimization technique differs from the literature (Naaijen et al., 2006), namely by the analysis of vertical 8-shaped trajectories (Dadd, 2011) which enable significant upwind benefits, as shown in Section 4. At last, to ensure the use of real validated data, kite aerodynamic parameters were taken from Dadd experiments (Dadd et al., 2010, 2011). In the second part of the study, the kite modelling approach was implemented into a dynamic velocity prediction programme (DVPP) (Roncin and Kobus, 2004) for an 8 m one design yacht, the Beneteau First Class 8. Validity of the DVPP was assessed by sea trials comparisons that are presented and discussed. The comparison between classical rig and kite propulsion is presented and discussed in the two last sections, based on velocity polar diagrams and on upwind and downwind legs.

2. Modelling approach of a flying kite

This section presents the setting technique used to describe the kite within the flying window. This enables kite velocities descriptions which are the main input data for the velocity comparison strategy with a classical sailing rig presented in this study.

2.1. Wind window reference frames

An illustration of the kite within the half sphere wind window, which is bounded by the wind window edge, is shown in Fig. 1. In this figure O denotes the attachment point of the tethers to a reference point (ground or deck of a ship for instance, here we take the centre of gravity of the boat).

In case of a boat, the wind window is oriented by the relative wind velocity vector $\mathbf{V}_{WR}$ at each point. Pay attention to the fact

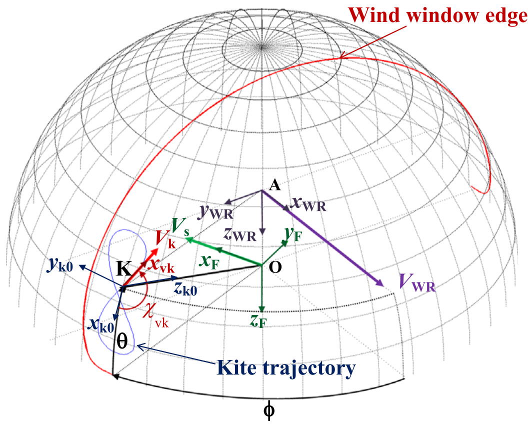

Fig. 1. Flying kite within the wind window. (For interpretation of the references to color in this figure, the reader is referred to the web version of this article.)

Download English Version:

https://daneshyari.com/en/article/1725533

Download Persian Version:

https://daneshyari.com/article/1725533

Daneshyari.com