INTERNATIONAL JOURNAL OF
NUMERICAL ANALYSIS AND MODELING
Volume 4, Number 3-4, Pages 548–558

SPEED WINDSURFING: MODELING AND NUMERICS

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This paper is dedicated to Professor Max D. Gunzburger on the occasion of his 60th birthday.

Abstract. We consider the following problem: Given a finite number of sails of different sizes with prescribed shapes, given the speed of the wind, the weight of a surfer, the size and shape of a surfboard and a corresponding fin; determine the sail and the course such that the windsurfer achieves maximal speed. We develop a simple model for describing the movement of the windsurfer for maximizing the speed in terms of a nonlinear ODE (ordinary differential equation). We conclude with the presentation of corresponding numerical results, some remarks on their validation and more involved models.

Key Words. Speed windsurfing, simple model, flow of air particles, nonlinear ODE, numerical simulation.

1. Introduction

A common goal for many windsurfers is to achieve enough speed for *planing*, a certain state of gliding over the water surface, provided that the waves are not too high. This state is, loosely speaking, comparable to throwing a flat stone over the water surface such that it hits the surface several times before sinking. Naturally, planing depends on the speed of the surfer which in turn depends on the size of the board and its fin and of the size of the sail.

In the following, we always assume that the surfer knows to surf with an optimal technique to reach the maximal speed and that his/her weight uniquely determines the strength with which he/she is able to hold the sail by means of the boom with both the hands and/or a harness, a device by which the full body weight is used to provide an additional 'anti'-force to the force generated by the wind in the sail and the fin in the water. Moreover, any experienced windsurfer knows which board to pick to balance between stability and speed: the larger the board, the stabler it is but also the slower, and vice versa.

It should be mentioned that the current world record of 48.7 kn (90.2 km/h) in the 10 sqm class has been achieved by Finian Maynard with a board of size 220 cm (64 ltr) with a 28 cm fin and a 5.0 m^2 sail; the weight of the surfer was 117 kg [8, 11]. This world record was achieved on April 10th, 2005, in the 'French Trench' near Les Stes. Maries de la Mer (France) where a certain artificial tunnel generates very high wind speeds and which is too narrow for the sea water to produce any waves. Thus, ideally, the maximal speed seems to be achievable with a large sail and high wind speed but a very flat water surface, which is a condition that hardly occurs in practice.

The present paper is concerned with modeling the movement of the windsurfer and with determining over a finite number of given sails of prescribed shape the

Received by the editors March 9, 2006, and, in revised form, March 23, 2006.

2000 *Mathematics Subject Classification.* 70F99, 65L06.

optimal sail by which the windsurfer can reach maximal velocity. Naively, one would think that the maximal speed will be caused by picking the sail with largest area of attack for the wind. However, the surfer needs to be able to hold the sail with hands and body weight, using a harness. That is, too large a sail for the weight and strength of the surfer might force him to fall into the water. In that situation, picking too large a sail may present an additional problem: in case of a sea level too deep for him to stand, he would have to use a water start which is very energy-consuming and, already after a few unsuccessful attempts, a dangerous enterprise, in particular, in case of offshore wind with high wind speed and large waves, which, in turn, often do not allow for a beginner-type basic start.

In summary, it is of vital importance for the practical surfer to pick the sail of the right size which allows him both for planing and, at the same time, is safe enough for him to use even in case of offshore wind. It is the purpose of the present paper to model and simulate this problem. Simultaneously, we wish to provide a program which runs on a common laptop computer at a beach station in an amount of time which is less than five minutes, an estimated time that an experienced surfer needs to switch the sail twice.

This paper is structured as follows. In Section 2, we introduce a basic model for the physical effects appearing in windsurfing and derive a nonlinear algebraic equation which gives the maximal speed of the windsurfer. Its approximate solution is described in Section 3, using Newton's second law and an explicit Runge-Kutta solver for the resulting nonlinear ODE. The numerical results are validated and discussed in Section 4, together with an outlook how to improve the basic model.

2. Modeling

Following the development of a first basic model in [9], we begin with notation and some physical assumptions.

We always assume that for some sea the speed of the wind $\overrightarrow{W_o}$, a board and a surfer with perfect technique are given.

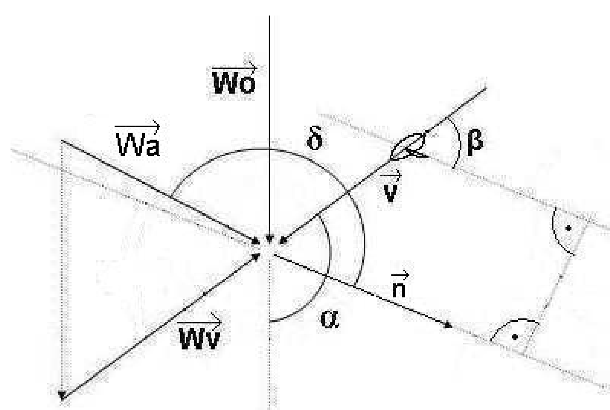

FIGURE 1. Movement of the surfer with local coordinate system.

The situation for modeling the movement of the surfer on the board is as follows. The surfer moves in direction $\overrightarrow{v}$ with angle α from the wind in downwind direction and holds the sail with angle β from the board, see Figure 1. Denote by $\overrightarrow{n}$ the vector for the position of the sail. Thus, α is the angle between $\overrightarrow{W_o}$ and $-\overrightarrow{v}$ and β the angle between $-\overrightarrow{v}$ and $\overrightarrow{n}$. All angles refer to the local coordinate system. The