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Development of a kayak race prediction including environmental and athlete effects

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Abstract

The aim of this study is to produce a simulator for sprint kayak racing which would allow the prediction of race times based on the physiological capabilities and mass of a given athlete. The simulator has been verified using established empirical data for the prediction of environmental effects and has been shown to be accurate, however verification of the physiological model is difficult to do by using general race data. An investigation into the fatigue model which has been implemented shows that further investigation is required to calibrate the simulator and produce more accurate results over a variety of distances. However, the simulator does show quite how sensitive the selection of appropriate level of effort is to the final race time for the 1000m.

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Keywords: Simulation, Sprint Kayak, race-time prediction;

1. Introduction

Sprint Kayak and Canoe events take place on a straight course on typically a wide expanse of water. The events are usually for a set of boats that commence from a standing start within their own delineated lanes. The purpose of the crew is to ensure that at any time during the race they are propelling the craft with the an appropriate effort such that they rapidly accelerate the craft to an appropriate speed, modify their stroke rate during the race and if deemed necessary respond to the efforts of the other crews such that they finish first. What is not clear is what is the most appropriate race strategy for a particular combination of crew and boat type for a given set of environmental conditions. One of the dangers is that the crew overexerts itself too early in the race such that later on they have insufficient reserves to respond to the efforts of other crews. Similarly that the perceived psychological benefit of being in front outweighs a more cautious strategy that attempts to manage crew effort.

The performance of the boat and crew will depend on a wide variety of factors. For instance the design of the equipment used, boats and paddles primarily, are governed by the individual event/sports rules and regulations

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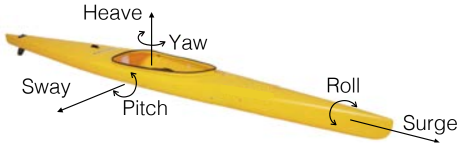

Fig. 1: Six degrees of freedom.

whereas, within certain constraints, the environmental effects of the winds strength, direction and variability, and resultant wind generated waves will all have an influence on the actual speed obtained by the participants. In this work a visual Matlab-Simulink based environment has been developed that allows a whole race to be simulated with multiple competitors. Appropriate Naval Architecture tools for the prediction of the performance of the boat in terms of its displacement, surface area, form and wave drag have been used for the resistance model with additional modelling applied for the influence of wind and waves on speed loss [6]. The crew members themselves are represented in terms of their mass and a model for the developed thrust of their individual stroke alongside a model for the maximum total and sustained effort [2].

2. RaceSim Development

2.1. Model Structure

The approach for the time-step simulation follows naval architecture practice for ship powering, manoeuvring and sea keepin [6]. The six degrees of freedom shown in Figure 1 can be reduced when considering powering alone to a balance of forces which establishes a mean drift, a fluctuating surge velocity and a model that captures the additional resistance components due to drift, added resistance in waves due to pitch, roll and heave, alongside wind loading. In this model the primary unsteadiness is due to the periodic impulse of the paddle action. The paddler is assumed to control the straight ahead motion through appropriate compensation left and right on opposing strokes.

Propulsive force, P, is entered as a function of time, and resistance is calculated based on a number of conditions including the speed, angle of drift, and size of the athlete. The net force is then used to calculate the acceleration of the kayak using Newtons Second Law of Motion where the effective mass includes that added due to the acceleration of the water. Both the kayak and athlete are assumed to be rigid bodies, and the force is being applied at the centre of mass of the kayak and athlete combined, reducing the model to 2 degrees of freedom in surge (x) and sway (y).

The acceleration was calculated by combining all of the resistance components and the propulsion model, to find a net force. The mass of the athlete and all equipment was then combined with the added mass of the kayak. The added mass is dependent on the projected area of the kayak in the water and so was calculated using an ellipsoid approximation for the submerged part of the hull, with formulae from [8]. The geometry is based on that of a representative competition kayak such that it's projected and surface area are known for different displacements, based on the mass of the athlete and equipment. The qualitative representation of the forces involved is,

$$(M + M_a)\,\ddot{x} = P(t) - \left[(1 + C_{aw}) \sum R_{hydro} + R_{aero} \right], \tag{1}$$

where $M + M_a$ is the mass plus added mass of the system, $\ddot{x}$ is the acceleration, P is the propulsive force as a function of time, t, C_{aw} is the coefficient of resistance added due to waves, including the effect of pitch roll and heave, $\sum R_{hydro}$ is the sum of the hydrodynamic resistance components and R_{aero} is the aerodynamic resistance. Once the acceleration is known it can be integrated to find the speed at the end of that time step, and integrated again to find the distance covered in that time step. Simulink uses an adaptive time step so that areas of the model which are changing rapidly have a smaller time step and higher accuracy, and more constant areas have a longer time step and therefore are less computationally expensive. This simulation uses the ODE45 solver and the time step is typically of order 0.001 seconds.