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Drag and power-loss in rowing due to velocity fluctuations

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Abstract

The flow motions in the turbulent boundary layer between water and a rowing boat initiate a turbulent skin friction. Reducing this skin friction results in better rowing performances. A Taylor-Couette (TC) facility was used to verify the power losses due to velocity fluctuations $P_{V'}$ in relation to the total power $\bar{P}_d$, as a function of the velocity amplitude A. It was demonstrated that an increase of the velocity fluctuations results in a tremendous decrease of the velocity efficiency e_V. The velocity efficiency e_V for a typical rowing velocity amplitude A of $20 - 25\%$ was about $0.92 - 0.95\%$. Suppressing boat velocity fluctuations with 60% will increase boat speed with 1.6%. Riblet surfaces were applied on the inner *and* outer cylinder wall to indicate the drag reducing ability of such surfaces. The results of the measurements at constant velocity are identical as the results reported earlier, while the experimental configuration was different. This confirms once more the consistency of the TC-system for drag studies. The maximum drag reduction *DR* was 3.4% at a Reynolds number $Re_s = 4.7 \times 10^4$, which corresponds to a shear velocity in this TC-system with water of $V = 4.7$ m/s. For typical rowing velocity fluctuations, the riblets maintain to reduce the drag with 2.8% and corresponds to a averaged velocity increase of 0.9%. The drag reducing ability of riblets is partly lost due to velocity fluctuations with high amplitudes ($A > 20\%$). From these results, it is concluded that the friction coefficient C_f will vary within one cycle. Higher acceleration/deceleration leads to a additional level of turbulent kinetic energy.

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Keywords: drag reduction, rowing, oscillation, efficiency

1. Introduction

Benefits of research in sport engineering are often considered as ”free seconds” in the world of sport athletes and coaches. The holy grail for many sport scientists is to develop a sport-dependent innovation or knowledge that may help the athlete to go faster, higher or stronger (”Citius, Altius, Fortius” [1]).

Many improvements and developments were accomplished in rowing over the last decades to achieve better performances. New generation materials (e.g. carbon fibers) and near-optimal boat design are nowadays common practice. Another interesting research topic is the interaction between boat surface and water, as $\pm$80-90% of the total hydrodynamic drag in rowing is caused by the turbulent skin friction [2,3]. Reducing this energy dissipation will result in a higher average velocity when maintaining the delivered mechanical power by the rower and consequently results in

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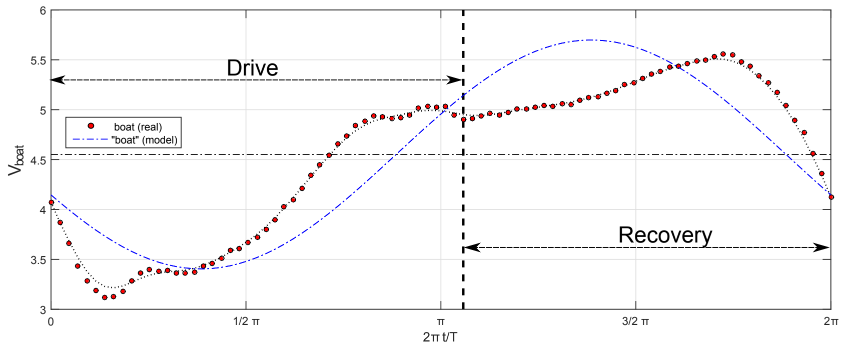

Fig. 1: Boat velocity of international lightweight single sculler[a]. Velocity amplitude A = 20-25% of the averaged boat speed $\bar{V}_{boat}$=4.6 m/s.

[a]www.worldrowing.com/athletes/athlete/42157/kuyt-conno

better performances of rowing athletes.
One solution to suppress the turbulent friction are drag reducing surfaces, which are frequently inspired by nature [4]. Superhydrophobic surfaces ("Lotus leaf" [5]) and riblets ("shark skin" [6]) are most applied subjects in these drag studies, while compliant coatings ("dolphin skin" [7]) are often overlooked.
General turbulent drag research are usually performed under constant bulk velocity in time. However, a rowing boat experiences velocity fluctuations during one rowing cycle (Fig.1), which may diminish the effect of the drag reducing surface. The boat velocity fluctuates because (1) the rowing cycle is devided in two phases (propulsion/drive and recovery phase) and (2) the rower moves relative to the boat and induce an acceleration of the boat in opposite direction of the acceleration of the rower [8–10].

The boat velocity V_{boat} can be decomposed into $V_{boat} = \bar{V} + V'$. The velocity fluctuations V' around the mean velocity $\bar{V}$ increases the total dissipated energy E_d of hydrodynamic drag on the boat in one rowing cycle (Eq.1 [8]). De Brouwer et al. [10] divide the total averaged power dissipated to drag $\bar{P}_d$ into useful power related to the mean velocity $P_{\bar{V}}$ and wasted power related to the velocity fluctuation $P_{V'}$. Minimizing velocity fluctuations V' results in a decrease of total dissipated energy E_d.

$$E_d = \bar{P}_d \Delta t = \int P_d \, dt = \int \frac{1}{2} \rho C_d S_b V^3 dt \tag{1}$$

In Equation 1, P_d is the needed power to exceed hydrodynamic drag (W), ρ is the water density (kg/m^3), C_d is the drag coefficient, S_b is the wetted boat surface (m^2) and V is the boat velocity relative to the water (m/s). The drag coefficient C_d is often improperly been considered as a constant value within one rowing cycle and based on the mean velocity $\bar{V}$. However, the periodic acceleration and deceleration of the fluid modifies the flow conditions in the boundary layer, resulting in a change of the turbulent kinetic energy and so the drag coefficient C_d within one rowing cycle.

In this paper we only focus on frictional drag, as it contributes the most to the total hydrodynamic drag on a rowing boat. The aim was to verify experimentally the relative power loss to velocity fluctuations $P_{V'}$ in relation to the power used $\bar{P}_d$, as a function of the velocity amplitude A. Hence, we have used a Taylor-Couette (TC) system that previously has shown to be a very accurate and compact facility to measure the frictional drag of surfaces [11]. Furthermore, we have investigated the influence of the velocity fluctuations on the drag reducing ability of riblet surfaces.