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Computational fluid dynamics analysis of drag and convective heat transfer of individual body segments for different cyclist positions

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ABSTRACT

This study aims at investigating drag and convective heat transfer for cyclists at a high spatial resolution. Such an increased spatial resolution, when combined with flow-field data, can increase insight in drag reduction mechanisms and in the thermo-physiological response of cyclists related to heat stress and hygrothermal performance of clothing. Computational fluid dynamics (steady Reynolds-averaged Navier–Stokes) is used to evaluate the drag and convective heat transfer of 19 body segments of a cyclist for three different cyclist positions. The influence of wind speed on the drag is analysed, indicating a pronounced Reynolds number dependency on the drag, where more streamlined positions show a dependency up to higher Reynolds numbers. The drag and convective heat transfer coefficient (CHTC) of the body segments and the entire cyclist are compared for all positions at racing speeds, showing high drag values for the head, legs and arms and high CHTCs for the legs, arms, hands and feet. The drag areas of individual body segments differ markedly for different cyclist positions whereas the convective heat losses of the body segments are found to be less sensitive to the position. CHTC–wind speed correlations are derived, in which the power-law exponent does not differ significantly for the individual body segments for all positions, where an average value of 0.84 is found. Similar CFD studies can be performed to assess drag and CHTCs at a higher spatial resolution for applications in other sport disciplines, bicycle equipment design or to assess convective moisture transfer.

1. Introduction

This paper deals with two important aspects of cyclist performance, namely aerodynamic drag and convective heat transfer from the body. Regarding the first aspect, 90% of the total resistance experienced by a cyclist at racing speeds (± 50 km/h in time trials) is caused by aerodynamic drag (Kyle and Burke, 1984), which is mainly related to the position of the cyclist on the bicycle. Many elite cyclists therefore try to optimise their position for drag by means of field tests or wind-tunnel tests. The resulting aerodynamic improvements are however mostly obtained by trial-and-error since usually only information on the overall cyclist drag is available. An alternative technique is computational fluid dynamics (CFD), which has already been applied for drag evaluation in cycling (Defraeye et al., 2010a, 2010b; Hanna, 2002; Lukes et al., 2004) and other sport disciplines (Dabnichki and Avital, 2006; Lecrivain et al., 2008; Minetti et al., 2009; Zaïdi et al., 2008, 2010). CFD can provide drag information at a higher spatial resolution, i.e. on individual body segments or bicycle components, which can increase insight in drag reduction mechanisms, especially when combined with the available flow-field data. A detailed overview and background on cyclist drag is given by Defraeye et al. (2010a, 2010b).

The second aspect of this paper, namely convective heat transfer, is required to assess the thermo-physiological response of cyclists, particularly for cyclist performance analysis related to heat stress (Tatterson et al., 2000; Wilson, 2004) and for hygrothermal analysis of clothing. This response is often analysed with thermoregulatory models (Tanabe et al., 2002; Wan and Fan, 2008) or clothing models (Qian and Fan, 2009). These models use empirically determined convective heat transfer coefficients (CHTCs; W/m^2K) to estimate the convective heat flux at the cyclist's surface ($q_{c,s}$; W/m^2) from the temperature difference between the surface (T_s; K) and the ambient air (T_{ref}; K): $CHTC = q_{c,s}/(T_s - T_{ref})$. Such CHTCs are essential in these models to quantify the (convective) heat exchange of humans with the exterior environment. CHTCs for humans are usually determined

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